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SMALL CONCRETE BRIDGES & CULVERTS

UNIVERSAL PORTLAND CEMENT CO.

Small Concrete Bridges and Culverts

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Foreword

DURING the last decade, confidence in concrete bridges has been growing steadily, but the great floods of 1913 crystallized public opinion in an instant and thousands of temporary structures demolished will be rebuilt largely of concrete.

For the purpose of assisting in the design and construction of concrete bridges, this booklet has been published. In it will be found general suggestions and designs as well as tentative specifications. Attention is particularly directed to the designs of several state highway departments which not only bear the stamp of authority, but indicate the general adoption of concrete for the construction of highway bridges and culverts.

While somewhat exhaustive data on the methods of building and the correct design of small concrete bridges and culverts have been published in this book, for the purpose of enlightening County and Municipal officials—yet the necessity for a competent engineer on larger structures, and also on the smaller ones when unusual conditions prevail, has been emphasized.

Public officials and engineers will, perhaps, find much of value to them in this book.

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Concrete Highway Bridges and Culverts

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Small Concrete Bridges and Culverts

Introduction

Historical

The construction of highway bridges in this country began to assume practical proportions about 1800. The first bridges were built of wood, at that time found in great abundance, and consisted of heavy timbers and planks roughly pinned together. They were built with little, if any attempt at economical design. An effort was made to protect the members by wooden sides and roof, but few were ever painted to preserve the timbers. Some of these wooden bridges are in existence to-day. The economical design of highway bridges was first investigated by Squire Whipple, of Utica, New York, who originated the Whipple truss and who published a book on the design of highway bridges about 1845.

Prior to 1850 few iron bridges were erected. The first metal bridges were of cast or wrought iron, and it was not until about 1870 that these materials were replaced by steel. Probably the first reinforced concrete bridge in this country was erected at San Francisco, about 1889 From this beginning, the use of concrete in bridge construction has grown, until to-day, progressive communities in every section of the country are adopting this type of construction.

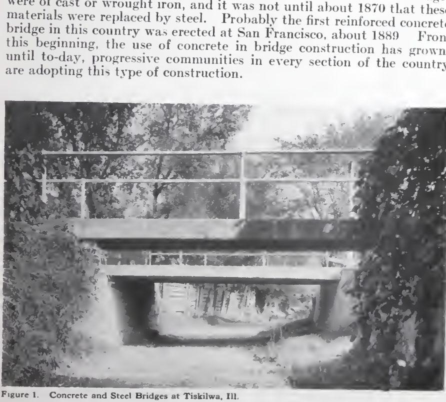


Figure 1. Concrete and Steel Bridges at Tiskilwa, Ill.

Purpose of The Book

Culverts and bridges stand in intimate relation to the improvement of the public highways, but the economy of building these structures of durable and permanent materials and according to intelligent, economic design, has not generally been recognized. While many communities still continue the old-fashioned, inadequate and expensive methods of construction and repair of their bridges and culverts, yet modern traffic conditions demand that the construction of bridges and culverts shall keep pace with the industrial development of the country.

The administration of road improvements in the United States is placed in the hands of local officials. The bridge improvements of many of these communities are mainly the construction and repair of culverts and small span bridges which do not justify the expense of securing the advice of an engineer. This book is intended to assist the local officials in securing a proper, intelligent and economic design for small bridges and culverts of less than 20-foot span.


Figure 2. Concrete Bridge, Kane County, Illinois.

Structures larger than 20 feet in span should never be undertaken without consulting an engineer. Many states maintain an engineer who will give free engineering advice to local officials requesting his services and the State Highway Commission should always be consulted by communities contemplating extensive bridge improvements.

Economic Considerations

The substantial construction of bridges is an important feature in the welfare of any community. Traffic conditions are demoralized by unsafe bridges and culverts. When considering the construction of a highway bridge, traffic conditions should be considered carefully and the bridge constructed not only to meet the present traffic requirements, but also that of the future. The bridge of to-day must be strong enough to allow the passage of heavy traction engines, road rollers and motor trucks. The bridge should advertise the progressive ideas and business activity of the community and therefore should be built of a structural material which is permanent and will not require costly items of repair every few years.

Advantages of Concrete

Concrete is peculiarly fitted for this construction. Concrete bridges are permanent and if properly constructed, cannot wash out; require neither painting nor repairing; are made of materials which can be purchased in the vicinity, and so permit the greater part of the cost of structure to be spent at home. For simplicity of

construction and durability, the concrete bridge leads all other types.

General Construction Data

A. R. Hirst, Acting State Engineer of Wisconsin, has prepared the following table, giving estimated cost of maintaining eight of the most common kinds of culverts over a period of one hundred years.

Table No. 1. Showing Cost of Maintaining Eight of the Most Common Kinds of Culverts Over a Period of 100 Years

KIND	Shape	Size	Cost	Cost for 100 Years
Wooden Box...........	Rectangle	15″ square	$16.80	$252.00
Concrete Box...........	Rectangle	15″ square	40.00	40.00
Cast Iron..............	Semi-circle	16″ diam.	57 90	97.80
Cast Iron..............	Sector	18″ diam.	65.25	112.50
Cast Iron..............	Circle	18″ diam.	92.40	166.80
Vitrified Tile...........	Circle	18″ diam.	42.00	42.00
Corrugated Steel.....	Circle	18″ diam.	50.40	196.00
Circular Concrete......	Circle	18″ diam.	35.00	35.00

Proper Location

After examining the foundation at a proposed bridge site, it is often found necessary to change the location of the bridge in order to secure a more suitable and economical foundation. In the layout of a new bridge site, attention should be given to the probable later improvement of the road, and this consideration should influence the position of the new structure. In all cases, the general alignment of the road should be planned so as to be practically straight. Short, sharp curves at the approaches of a bridge are to be avoided. It is not unusual to see a bridge built to fit the stream only, utterly disregarding the sharp turns necessary to approach it.

Foundations

The question of foundation is an important one, as upon it depends the stability of the whole structure. The word "foundation" is used to indicate the natural bed or soil upon which is placed the footings for the abutments of a bridge or the walls of a culvert. The amount of attention to be given the foundation will vary with the size and importance of the structure, upon the loads which it is to carry, and upon its type. No part of bridge construction requires more care and skill than the determination of the proper depth to the foundation and the construction of the footings.

The different foundations, ranging as they do from hard rock to the light loam soil of the prairie states, will vary greatly in their bearing power. Good judgment and experience aided by a careful study of the soil, should enable the practical man to determine with a reasonable degree of accuracy its supporting power. The safe supporting power of the various soils is given in the following table from "A Treatise on Masonry Construction," Prof. Ira O. Baker, of the University of Illinois."

Table No. 2

	Supporting Power in Tons per Sq. Ft.
Rock—in thick layers, in natural bed	200
Clay—in thick beds, always dry	4
Clay—in thick beds, moderately dry	2
Clay—soft	1
Gravel and coarse sand, well cemented	8
Sand—compact and well cemented	4
Sand—clean and dry	2
Quicksand, loam soils	0.5

For a rock foundation, it is, as a rule, only necessary to cut away the loose and decayed portions of the rock and prepare a surface as nearly as possible at right angles to the direction of the pressure. For foundations other than natural rock, it is necessary to see that the footings are below the frost line and that the foundation has sufficient bearing power to sustain the loads which will act upon it. Moreover, in soils of this character, care must be taken to see that the abutments are protected against undermining by currents of water.

When the structures are to be located in soft or swampy ground, where it is impossible to secure a firm, natural foundation, special forms of foundations are necessary such as wooden piles or reinforced concrete floors which distribute the weight over a greater area. In instances of

Figure 3. Concrete Bridge, near Oregon, Illinois.

this kind, each case must be taken as a separate engineering problem of its own, and knowledge of the best method to be employed can only come with experience.

Determination of Size of Waterway

The determination of the size of waterway required is a problem that does not admit of an exact calculation; however, it is a matter which demands intelligent consideration. If the waterway of a culvert or bridge is too small, it is liable to cause a washout, entailing interruptions to traffic and costly repairs. On the other hand, if it is too large, the cost of construction is unnecessarily increased.

Although there are several theoretical formulas for determining the area of waterway for small bridges and culverts, none of them gives close and accurate results, and they are used more as an "aid to the judgment, than for actual results." The span and height of a bridge or culvert can best be determined by careful observation of the stream and the amount of water which it carries at flood times. A cross section of the stream at some narrow place should be measured at a time of high water. This will enable one to determine the proper area of waterway with a reasonable degree of accuracy.

Figure 4. Concrete Bridge, McLean County, Illinois. 12-foot span; 16-foot roadway; Cost $300.

Types of Bridges

Concrete bridges may be classified as slab or girder bridges and arch bridges. Slab and girder bridges are those in which the pressure from the bridge floor acts vertically upon the abutments. They consist either of flat slabs or of combined beams and slabs of concrete reinforced with steel. Arch bridges are curved, and the pressure upon the supports is not vertical but inclined. Flat slab construction is suitable in level countries and for locations where the foundation is of soft material. Arches are especially economical in localities where the roads can be built at a considerable height above the streams and where there is rock, gravel or similar hard soils which offer solid foundation.

A flat slab bridge consists essentially of a concrete floor of uniform thickness reinforced with steel and resting on the abutments. The re-

inforcement in the slab consists of steel rods running lengthwise of the roadway, which take up all tension stresses due to loads on the bridge, while rods are run at right angles to the roadway to reinforce the slabs against temperature stresses. The distance from the bottom of the slab to the top of the footing should vary to meet the requirements of the waterway.

The arch bridge consists of a curved slab the thickness of which increases from the crown to the springing line. The arch may either be elliptical or semi-circular in shape, of plain concrete or reinforced with steel rods. Each span of both types is a special design in itself, and it is necessary to have exactly the correct amount of concrete and steel rods for each individual design.

Figure 5. Concrete Culvert on a road leading to Indianapolis along the right of way of the Pennsylvania lines.

Culverts The term, culvert, is generally applied to structures built to provide waterway through high embankments or to carry surface water from one side of the roadway to the other. The term, bridge, is given to those structures spanning natural waterways. Authorities disagree as to the dividing line between the two. One authority applies the name, culvert, to any structure less than 30 feet in span, while another limits the name to any structure under 6 feet in span. For convenience, a culvert will be considered as 8 feet and less in span, while all structures over 8 feet in span will be classed as bridges.

The bridge and culvert designs shown in Figs. 17 and 25 are for loads as follows: Dead loads, concrete 150 lbs. per cubic foot, earth fill, 100 lbs. per cubic foot, a uniform live load of 125 lbs. per square foot, and a concentrated load of 24 tons on two axles 10 feet apart, 8 tons on the front and 16 tons on the rear axle. This load was considered as acting over a width of 12 feet. The moment for both the uniform live load and the concentrated load was calculated and the greater added to the dead load moment to determine the dimensions of the slab.

The compression allowed in concrete has been taken at 600 lbs. per square inch for concrete 60 days old, with a corresponding stress in steel in tension of 16,000 lbs. per square inch.

In designing the arch bridge and culvert shown in Figures 19 and 29, the empirical rules indicated by the best American practice were used to obtain thickness of crown and springing line. The line of resistance of the arch was then determined and located graphically on the profile of the arch. This line of resistance was determined for different live loadings and found to lie within the middle third.

Selection of Aggregate

The materials mixed with the cement to form concrete, are commonly referred to as "aggregates." Careful selection of all aggregates is necessary to obtain good concrete. They must be clean, coarse, hard and well graded. Clean, because if the separate particles are covered with a coating or film of any kind, the cement cannot form a bond with them. Coarse, because a coarse aggregate presents a smaller surface for the same volume than a fine one, thus making a stronger concrete with the same proportion of cement.

Concrete is no stronger than the aggregate composing it, consequently the aggregate must be hard and remain hard under all weather conditions. Some sands and gravel contain shale-like particles which, after exposure to the weather for a short time, go to pieces. Occasionally, stone which is not hard or is of a chalky nature, is crushed for use in concrete and naturally will not give good results.

The aggregate must be well graded. An ideal aggregate is one which contains just enough of different sized particles to produce a mass with a minimum amount of voids or air spaces and possesses, at the same time, a maximum amount of coarse material.

Those particles of the aggregate which will pass a one-quarter inch sieve are generally considered as sand. Sand must be free from an excessive amount of fine material. A mixture of cement and fine sand cannot possibly give as great strength as a mixture of the same proportion of cement and coarse sand; therefore, the use of fine sand should be avoided. If it is the only sand at hand, a coarse material should be obtained to mix with it, or a correspondingly larger proportion of cement used.

The coarse aggregate, either screened gravel or crushed stone, should all be coarser than one-quarter inch. In reinforced concrete work, where the shape and position of the reinforcing steel must be considered, the size of the aggregate should be such that the concrete can readily be placed about the steel. In ordinary work, 1½-inch gravel or stone will be as large as can be used.

Proportioning

The materials should be proportioned accurately. One sack of cement (94 pounds net), is considered one cubic foot, and each batch of concrete should be some multiple of one sack. The practice of shoveling sand and gravel directly upon the mixing platform or into the mixer without measuring, should never be permitted. It is best to measure materials in an accurate manner. This can be accomplished by measuring them in wheelbarrows, the capacity of which has been previously determined, providing care is taken to see that the wheel barrows are properly loaded each time.

In many communities it is common practice to use gravel as it comes from the gravel bank, even though the amount of fine material or sand

contained is very much larger than it should be. This material, as it comes from the natural bed or deposit, is seldom suitable for concrete without screening. The sand is in too large proportion, and in order to obtain the best results, the gravel should be screened and the sand and coarse aggregate remixed in the proper proportions. The relative proportions of sand and coarse aggregate in a mixture are as important as the proportions of cement, and should not be guessed at, but definitely determined.

To make this bad practice worse, it frequently happens, when the amount of fine and coarse material for the concrete is specified and unscreened gravel is used, the sum of the parts of the coarse and fine material is incorrectly taken as the amount of unscreened gravel permissible. A mixture composed of one part of cement and six parts unscreened gravel, is by no means the same as one composed of one part cement, two parts sand and four parts screened gravel or crushed stone. Even though the unscreened gravel contained the proper proportion of fine and coarse material, a 1:6 mixture of such a material would be approximately the same as one composed of one part cement, three parts sand and six parts coarse aggregate, that is, three cubic feet of sand and six cubic feet of gravel when mixed together make but little more than six cubic feet of material.

Proportions for Bridge Work The concrete for the abutments of bridges and for the sides and footings of culverts, should be proportioned 1 sack Portland cement, $2\frac{1}{2}$ cubic feet of sand and 5 cubic feet of screened gravel or crushed stone. For bridge and culvert floors and guard rails and also for the arch ring above the springing line, these proportions should be 1:2:4.

Figure 6. Flat Top Concrete Bridge with ornamental iron guard rail, near Geneva, Illinois.

Mixing

The mixing is just as important as any other part of the process of making concrete. After the proper materials have been selected and the proper proportions determined, the mixing must be done in a manner which will insure the covering of every particle of sand with cement and every particle of gravel or stone with the cement-sand mortar.

Where necessary to mix by hand, the sand should be spread upon a level watertight platform to a uniform depth. The cement should be spread evenly over the sand and the two mixed until the mass is uniform in color. On this mixture should be spread the required amount of gravel or stone which has been previously drenched, and the entire mass mixed until the coarse aggregate is uniformly distributed throughout the batch. Water should be added and the entire mass thoroughly mixed.

A machine mixer is much more certain and reliable than hand mixing, because the thoroughness of mixing is not dependent upon the fatigue or carelessness of the workmen, and therefore, each batch will be mixed uniformly.

The quality of the concrete depends largely upon the amount of water used. Generally speaking, wet concrete will give better results than dry. A dry mixture is not capable of developing all the strength of the cement and will result in a weak and porous concrete. On the other hand, an excess of water is often added when the same consistency could be secured by more thorough mixing. It will be noticed that the mass of concrete becomes more moist as the mixing proceeds, which shows that the particles are being forced in closer contact and that the object of the mixing is being accomplished. The materials should be mixed with sufficient water to form a concrete of such consistency that when placed in the forms and slightly tamped, it will quake like jelly.

Care should always be taken when adding water to the mixture. When mixing by hand, it is excellent practice to add the water in a spray such as can be obtained by the use of an ordinary sprinkler. The water should never be dashed from a bucket on the pile of materials and the mixing should always be conducted in a manner which will not permit the loss of cement through the running off of the surplus water.

The concrete should be placed in the forms as quickly as possible after being mixed, and the speed with which the concrete can be placed should govern the size of the batch. Under no conditions should concrete which has partially hardened be used.

Forms

The cost of concrete bridge work is, to a considerable extent, influenced by the expense attending the construction of the forms. The average carpenter who has not had experience in this class of construction, will, unless properly directed, greatly increase the cost A man not familiar with concrete form construction will invariably use too many nails, thus increasing the cost of removing the forms, also resulting in ruining a large amount of lumber for future use. A good rule to observe in construction of forms, is to avoid the use of nails whenever possible. Then too, the inexperienced man does not realize the enormous weight the forms have to carry and therefore, fails to make the centering sufficiently strong, allowing it to bulge and sag.

Any slight settlement of the forms occurring after the concrete has been deposited and before it has hardened sufficiently to sustain its own weight, is detrimental to the structure.

Improper bracing causes much loss of time and unsightly work. Many braces, however, can be done away with by using bolts. This applies particularly to the forms for abutments and wing walls where the opposite sides can be tied together by bolts or wires, thus causing the form on one side of the wall to help hold the opposite form in place. Proper methods of form construction and careful handling will save much lumber and allow the forms to be used several times. Where possible, the forms should be held and fitted into place by wedges which should be made of hardwood, well fitted and carefully driven to avoid shock. If the forms are supported upon a muddy creek bottom, it is necessary to place them on a firm foundation so that any strains on the new concrete due to settlement, may be avoided.

The face forms should be made of 2-inch lumber, sound and free from knot holes or other defects, and must be constructed so that they will be held rigidly in place. Where knot holes are unavoidable, they should be plugged with damp clay immediately before filling, or covered with a small piece of tin or building paper on the inside of the form. The inner face and both edges of the lumber should be dressed to insure a smooth finish on the exposed surface of the concrete and prevent ridges due to lack of uniformity in thickness of lumber. When the edges of the boards are not dressed, it is impossible to fit them closely together, thus permitting the cement mortar to leak through the cracks. These cracks will also cause unsightly ribs and ridges on the face of the finished structure. The forms should be cleaned carefully after each removal and

Figure 7. Flat Slab Bridge, Wayne County, Michigan. 7-inch slab; 8-foot span; 18-foot roadway. This view shows forms in place and method of bracing.

just before using again, it is advisable to treat or dress the face of the form with soap, paraffine or oil to prevent the mortar from adhering.

Time to Remove Forms

The weather has a decided effect upon the rate of hardening of concrete, thus a direct influence upon the time which the forms should remain in place. In the cool weather of spring and fall, concrete hardens slowly, so that the forms may need to remain several weeks before removal. Even in summer, during cool and cloudy weather, forms sometimes cannot be removed for several days.

Under the most favorable weather and construction conditions, no forms should be removed within less than 48 hours after depositing the concrete. For arches and floor slabs the forms must remain much longer than for the end and wing walls. The supports for floor slabs and arches must remain in place at least 28 days. Removing forms too soon has been the cause of more accidents than any other one thing; therefore, this is a point which should be considered carefully. It is the practice in some places to require, before removing the form, that the concrete in slabs and arches be sufficiently hard to cause a 20-penny spike driven into the concrete to double up before it has penetrated one inch.

Placing of Steel

When the forms have been erected and carefully measured, insuring that everything is true and to the line, the steel may be placed. In placing steel it is necessary to keep strictly to the design and see that pieces of the proper size are placed exactly as shown and carefully wired into position. Workmen are apt to be careless in placing steel and neglect the wiring together of the rods because it is a little tedious. Too much care cannot be exercised in this work for a rod in a certain position will perform an important function adding strength

Figure 8. Flat Slab Bridge, Wayne County, Michigan. 9-inch slab; 12-foot span; 18-foot roadway, reinforced with 1-inch twisted bars, on 11-inch centers. Cost $400.

and stability to a structure, while if allowed to shift a short distance, may be absolutely worthless besides leaving the structure weaker than it would otherwise be. The steel must be free from grease, dirt, or rust scale, when placed, because the presence of any of these on the steel will prevent the bonding of the steel and concrete. After the steel is placed, all dust and dirt should be removed and the forms thoroughly wetted before pouring the concrete.

Placing of Concrete

The concrete should be deposited carefully in place so that the aggregates and mortar will not become separated. The mass of concrete should be kept practically level, otherwise the water will drain from the concrete at the high places, carrying a portion of the cement with it. As the concrete is placed, it should be tamped, and that portion next to the form should be "spaded" thoroughly by using a specially designed flat-faced tool to force back the larger particles of the aggregate and bring the mortar in contact with the form. A spading tool of this characteer can be made from a hardwood board 1 inch by 4 inches, gradually sharpened to a chisel edge at the end. The sharpening should be on one side only and in using this paddle, the flat side should be placed against the form. This thorough spading of the concrete next to the forms is important as the smooth finish of the exposed surfaces depends upon the care with which the spading is done. The mixture must be quite plastic, as a dry mixture would have no tendency to flow. Concrete in the abutments should be deposited in continuous horizontal layers, thus avoiding any vertical joints. In the floor slab, the concrete should be placed for the full thickness of the slab at one time.

Where it is impossible to construct the abutments in continuous horizontal layers, it is best to divide the work in sections and complete each

Figure 9. Concrete Bridge, Town of Gorham, Ontario County, New York. Designed by New York Highway Commission. Span 18 ft. 6 in., Roadway 23 ft. Built by town labor. Cost $188.

section without interruption. This will make it necessary to provide for vertical joints at both ends of the section. So that the sections of the abutment will be keyed into each other, a groove should be formed in one end of each section. This groove can be made by placing a 4 x 8 timber vertically against the end wall of the form and removing before depositing the next section. Previous to placing, the 4 x 8 timber should be dressed slightly wedge shaped, so that it can be removed without destroying the groove.

For reinforced work it is necessary to use a slushy concrete. It should not, however, be so wet that the mortar is watery or will run away from the coarse aggregate leaving pockets in the finished work. The concrete should be "joggled" rather than tamped so that it will flow under and around the steel and will flow into place without disarranging the steel. Care must also be taken to see that the steel does not separate the larger particles of the aggregate from the mass.

Wherever concreting is unavoidably interrupted even for a short time, a weakened bond will occur between the new concrete and that previously placed unless special precautions are taken. The surface of the old concrete should be thoroughly wetted and a grout of cement and water mixed to the consistency of thick cream spread immediately before additional concrete is placed. Under no circumstances should this grout be allowed to become dry. The amount of water that will be required to wet the old concrete will depend upon a number of conditions, but its tendency to absorb water must be satisfied.

It often happens that at the beginning of a day's work, a white or yellowish soapy deposit is found on the surface of the previous day's concrete. This deposit is known as "laitance" and must be removed from the surface in order to secure a proper bond between the two days' work. Laitance occurs when concrete is mixed with an excess of water or is agitated excessively, or both, and is composed largely of very fine particles of cement separated from the concrete by the excess water. These fine particles in suspension in the water lose their life before they come to rest and are left on the surface of the concrete an inert mass when the water disappears.

Finish

In ordinary bridge work, the expense attending an artistic surface finish is hardly justifiable, and the surfaces are usually left as they are found upon the removal of the forms. The concrete takes the impress of flaws in the face of the forms and shows the grain marks of the lumber. Careful workmanship and good forms can do much toward getting a satisfactory finish, which again emphasizes the importance of using good tight fitting lumber of uniform thickness, dressed on one side and both edges. Care should also be taken during the removal of the forms to see that the edges of the work are not broken, nor the surface injured in any way.

Painting with a cement grout after the removal of the forms is sometimes resorted to, but it is not recommended, for unless it is done with great care, it will scale off after a short time, leaving the surface rougher and more unsightly than it would have been if not touched.

In public parks and private estates, where a more artistic finish is desired, some further method of surface treatment is necessary. The most common and effective methods are by brushing, etching with weak acids, or bush hammering. A complete description of these methods is given in "Concrete Surfaces," published and distributed by the Universal Portland Cement Co.

Figure 10 Concrete Bridge, Town of Canandaigua, Ontario County, New York. Designed by New York Highway Commission. Span 14 ft., Roadway 26 ft. Built by contract. Cost $950.

Abutments

The abutment of an ordinary highway bridge or culvert has two offices to perform; to support one end of the structure, and to keep the earth embankment from sliding into the water. The form of abutment to be adopted will depend upon the locality, but the wing abutment will be found to be most economical under ordinary conditions. In the wing abutment, the end wall acts as a support for the bridge and a retaining wall for the earth embankment, while wing walls which act as retaining walls only, are placed at an angle to the end wall of the abutment.

Typical Design for Abutment Forms

Figure 11 shows an end section of a wing wall and illustrates the method of placing and bracing the forms. The distance between wall forms is maintained by separator rods and twisted wires passing around the studding as shown in the figure. The wing walls for the bridge and culvert designs shown are of a typical design and the details shown in Figure 11 can be used with all.

Proportions

The proportions of the materials for plain concrete abutments as shown in the following designs should be 1 sack of Portland cement, $2\frac{1}{2}$ cubic feet of sand and 5 cubic feet of screened gravel or crushed stone. These materials should be selected and mixed as described in the section under aggregates.

Angle of Wing Walls

The angle of wing walls to be adopted in any case will depend upon local conditions, whether the banks are low and flat or steep and rocky, and also whether the current is swift or slow. The more the wing departs from the face of the abutment as it swings around into the embankment, the greater the length required and the greater the

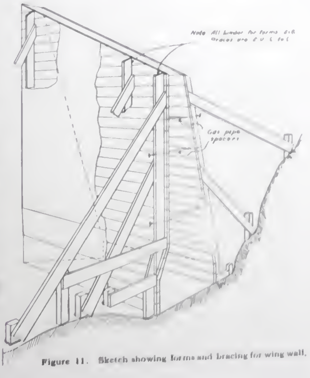


Figure 11. Sketch showing forms and bracing for wing wall.

thrust upon it. In the following designs for bridges and culverts, the wing walls are shown at an angle of 30 degrees to the direction of the stream flow. While this angle should be made to suit local conditions, 30 degrees will be found the most satisfactory for ordinary conditions. In no case has it been found practical to place the wings at an angle greater than 45 degrees.

The lengths of the wing walls will be governed largely by local conditions such as the character of the banks and the depth necessary to secure a good foundation. In the table of quantities accompanying each design, a definite length for the wing walls was assumed. This was necessary in order to obtain the quantities given in the tables, and the lengths assumed will undoubtedly be found the most economical under all ordinary conditions.

Drainage

Since there is always a considerable amount of loose earth fill back of the abutments, it is advisable to provide drain or weep holes through the abutments. This will prevent the collection of water back of the abutment which might prove extremely dangerous to the stability of the structure during cold weather, due to expansion of the water when freezing. A small drain placed in both wing walls and end walls about one foot above the normal water level of the stream will be sufficient.

Standard Width

The standard width of highway bridges varies in different sections of the country. In practically all the middle western states, the width is 16 feet; in some of the southern states 12 is not unusual, while in the eastern states 24 feet has become customary.

The width of a highway bridge depends upon the amount and character of the traffic which it must carry and to which it will be

Figure 12. Concrete Culvert, Town of West Bloomfield, Ontario County, New York. Designed by New York Highway Commission. Span 4 ft. Roadway 22 ft. Cost $375. Culvert has been built at an angle to the axis of the stream flow.

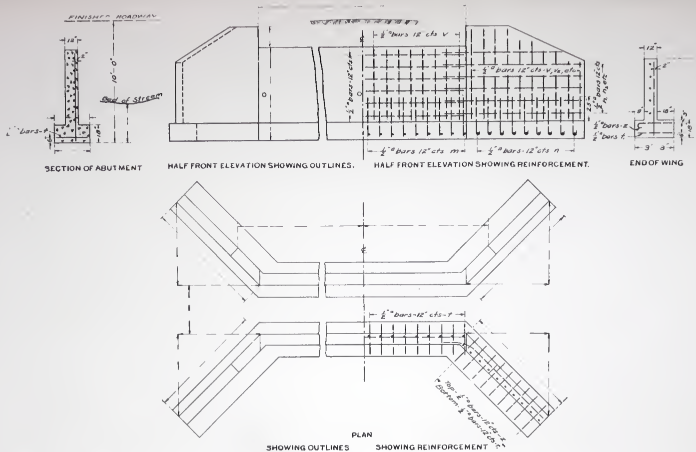


Figure 13. Concrete Sub-structure of 10 feet over all height. Designed by the Illinois Highway Commission.

subjected in the future. This question should be considered carefully by a community when constructing a bridge of such permanent material as concrete. While the designs show a standard width of 16 feet, this width may be increased to accommodate the traffic. In no case should a bridge be built with less than a 16 foot roadway.

While the designs are for plain concrete abutments, it may be found at times more economical to use reinforced abutments. Figure 13 shows a standard reinforced concrete sub-structure designed by the Illinois Highway Commission. This type of reinforced sub-structure is used where the wings can be swung nearly parallel to the axis of the roadway. No dimensions are given for the length of the wing walls nor base of the abutment for the reason, as has been previously stated, that these dimensions are influenced by the character of the stream banks. The following table gives size and length of steel reinforcement required.

Note—

Use two thicknesses of building paper between adjacent surfaces of substructure and superstructure.

In the elevation the wing is swung parallel with face of abutment to show reinforcement.

All exposed edges of wings to be beveled with $\frac{3}{4}$ inch triangular molding.

Place 3-inch tile drains in abutment walls one foot above ground line at abutment.

Concrete to be proportioned 1:2½:4.

Reinforcement to be round soft steel rods.

Bill of Material

Letter	No.	Size	Length
V	.	½″	. . .
V1	.	½″	. .
V2		½″	. .
V3		½″	. . .
H		½″	. . . . .
H		½″	. . . .
M		½″	3′ 6″
N		½″	4′ 0″
T		½″	. . . . . .
T1		½″	3′ 0″
Z	.	½″	3′ 6″

The reinforced abutment will contain a much smaller amount of concrete and will, therefore require considerably less excavation. However, the cost will be increased because of the cost of the steel and the additional work required in placing the steel and the concrete in the narrower space between forms. The plain concrete abutment is more simple in construction and under all ordinary conditions will be found more economical.

Slab Bridges

As has been previously stated, slab bridges consist either of flat slabs or of combined beams and slabs of concrete reinforced with steel. For spans 20 feet and less, flat slabs or slabs without beams are the most economical, the more simple of construction, and will therefore, be the only type considered in this book.

In the prairie country, the stream gradients are generally flat, the water course is crooked and the banks low, at least upon one side. For these water courses, where the head room is limited, the slab type of bridge or culvert is preferable to the arch. These streams will usually be out of their banks and flowing over road grades before using much head room, therefore, a waterway sufficient to take the ordinary flow will be entirely adequate.

In flat country the foundation is usually light soil, as rock seldom approaches near enough to the surface to found abutments upon it. Under these conditions the slab bridge which carries the load vertically upon the foundation is to be preferred to an arch bridge which carries the load at an angle. Moreover, a slab bridge is less liable to suffer damage due to any slight settlement of its abutments, while the least displacement of the abutment of an arch endangers its stability.

Forms

The forms for the reinforced slab bridge floor are so simple in construction that no detailed description is necessary. The important thing to remember is the enormous weight which the forms will be required to support. The floor slab for a 20-foot span with 16-foot roadway will weigh approximately 50 tons. The supporting

Figure 14. Heyman Bridge on the Hunts Corners Road near Monroeville, Ohio.

shores and lagging sustain this weight and must be designed accordingly. Where a muddy creek bottom is encountered, the shores must rest on a firm foundation so that no settlement will occur.

Abutments

The dimensions of the end and wing walls depend upon the value "H" or the height of the bridge floor above the top of the footing. The value of "H" is entirely independent of the span and is in-fluenced by the local conditions existing at the site of the bridge. It depends upon the depth neccessary to secure a firm foundation and the amount of head room required to accommodate the stream flow. The footings must in all cases be carried to a foundation having sufficient bearing power, as described in the section on foundations, page 7.

Table 3 gives the dimensions of the end and wing walls for the varying values of "H." In all cases the length of the wing walls has been taken as equal to "H". The top of the wing wall is given a slope of one foot in every two feet, that is, for any value of "H", the height of the end section of the wing wall should be one-half of "H." The concrete for the abutments should be proportioned as previously described under "Abutments," page 13.

Bridge Seat

As indicated in Figure 17, two thicknesses of building paper should be placed between the adjacent surfaces of the abutment and the bridge floor. This prevents any bond between the sub-structure and superstructure, and gives a bridge floor with both ends free. Without such a precaution, the top of the abutment will be subjected to excessive strains due to the expansion and contraction of the bridge floor from temperature changes.

Figure 17 shows a design for a flat slab bridge of spans from 8 to 20 feet. The thickness of the floor slab required for the various spans to-

Figure 15. Concrete Bridge, Silver Lake Township, Martin Co., Minnesota. 20 foot span. 18-foot roadway Cost $734.

Table No. 3 To Accompany Table No. 4. Dimensions of Abutments and Amount of Materials

Note—H Depends on Location, not upon Span.

ABUTMENTS					SPAN							
End Walls			Wing Walls									
H	B	C	L	G		8	10	12	14	16	18	20
5	2′- 0″	2′- 6″	5	2′-0″	Abutment	22.0	22.0	22.0	22.0	24.6	24.6	24.6
					Floors and Guard	7.4	9.9	12.4	16.0	21.1	25.1	29.4
					Cement	38.6	42.8	46.5	51.5	62.0	68.5	74.9
					Sand	13.3	14.7	15.8	17.5	21.0	22.8	24.7
					Gravel	26.6	29.4	31.6	35.0	42.0	45.6	49.4
6	2′- 5″	3′- 3″	6	2′-0″	Abutment	31.2	31.2	31.2	31.2	34.4	34.4	34.4
					Floors and Guard	7.4	9.9	12.4	16.0	21.1	25.1	29.4
					Cement	50.1	53.8	57.6	57.6	74.6	80.7	87.1
					Sand	17.7	18.9	20.0	21.7	25.5	27.4	29.3
					Gravel	35.4	37.8	40.0	43.4	51.0	54.8	58.6
7	2′-10″	3′-10″	7	2′-0″	Abutment	41.0	41.0	41.0	41.0	44.8	44.8	44.8
					Floors and Guard	7.4	9.9	12.4	16.0	21.1	25.1	29.4
					Cement	62.3	66.0	69.8	69.8	87.6	93.7	100.1
					Sand	22.3	23.4	24.6	26.2	30.3	32.2	34.1
					Gravel	44.6	46.8	49.2	52.4	60.6	64.4	68.2
8	3′- 2″	4′- 2″	8	2′-6″	Abutment	51.0	51.0	51.0	51.0	55.2	55.2	55.2
					Floors and Guard	7.4	9.9	12.4	16.0	21.1	25.1	29.4
					Cement	74.9	78.6	82.3	82.4	100.6	106.7	113.1
					Sand	26.8	28.0	29.2	30.8	35.1	36.9	38.9
					Gravel	53.6	56.0	58.4	61.6	70.2	73.8	77.8
9	3′- 7″	4′-10″	9	2′-6″	Abutment	64.6	64.6	64.6	64.6	69.4	69.4	69.4
					Floors and Guard	7.4	9.9	12.4	16.0	21.1	25.1	29.4
					Cement	91.8	95.5	99.3	99.3	118.3	124.4	130.8
					Sand	33.1	34.3	35.4	37.1	41.6	43.5	45.4
					Gravel	66.2	68.6	70.8	74.2	83.2	87.0	90.8
10	4′- 0″	5′- 6″	10	2′-6″	Abutment	80.4	80.4	80.4	80.4	85.4	85.4	85.4
					Floors and Guard	7.4	9.9	12.4	16.0	21.1	25.1	29.4
					Cement	111.6	115.3	119.1	119.1	138.3	144.4	150.8
					Sand	40.4	41.5	42.7	44.3	49.0	50.8	52.8
					Gravel	80.8	83.0	85.4	88.6	98.0	101.6	105.6
					Top of Abutment S = 12″					Top of Abutment S = 18″		

Note—All quantities in above table are given in cu. yds. except cement which is given in bbls.
Concrete—For Floor Slab 1:2:4. For Abutments 1:2½:5.

Table No. 4, Reinforcement for Flat Slab Bridge, 16-Ft. Roadway, Computed for 24-Ton Roller

Span	Slab Thickness	Depth of Concrete Below Steel	FLOOR SLAB.								GUARD RAILS (Both)								Diagonal Rods
			Tension Steel				Temperature Steel				Horizontal				Vertical				
			No.	Size	Spacing	Length	No.	Size	Spacing	Length	No.	Size	Spacing	Length	No.	Size	Spacing	Length	No.
8'	9 "	1 "	43	5/8"	5 "	11'	9	5/8"	12"	18'	6	1/2"	15"	9'	10	1/2"	24"	3'-6"	20
10'	10 1/2"	1 1/4"	33	3/4"	6 1/2"	13'	7	3/4"	18"	18'	6	1/2"	15"	11'	12	1/2"	24"	3'-6"	24
12'	11 1/2"	1 1/4"	39	3/4"	5 1/2"	15'	8	3/4"	18"	18'	6	1/2"	15"	13'	14	1/2"	24"	3'-6"	28
14'	13 1/2"	1 1/2"	43	3/4"	5 "	18'	12	3/4"	15"	18'	6	1/2"	15"	15'	16	1/2"	24"	3'-6"	32
16'	15 1/2"	1 1/2"	47	3/4"	4 1/2"	20'	17	3/4"	12"	18'	6	1/2"	15"	17'	18	1/2"	24"	3'-6"	36
18'	17 "	1 3/4"	31	1 "	7 "	23'	12	1 "	18"	18'	6	1/2"	15"	19'	20	1/2"	24"	3'-6"	40
20'	18 1/2"	1 3/4"	33	1 "	6 1/2"	25'	21	1 "	12"	18'	6	1/2"	15"	21'	22	1/2"	24"	3'-6"	44

Note:—

Round soft steel used for all reinforcement

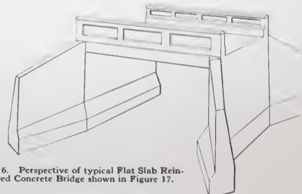


Figure 16. Perspective of typical Flat Slab Reinforced Concrete Bridge shown in Figure 17.

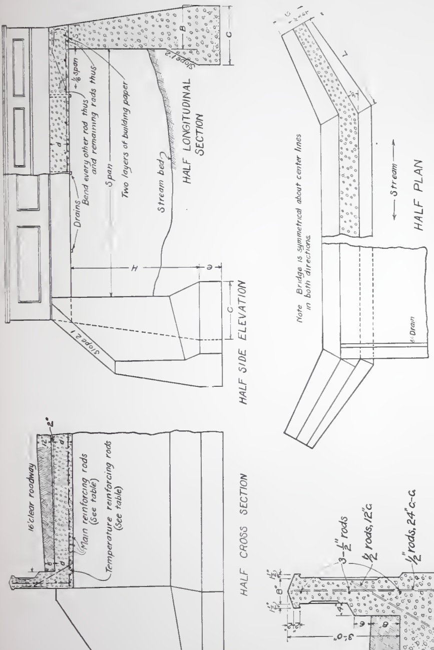


Figure 17. Typical Flat Slab Design. Reinforced Concrete Bridge, 8 to 20 feet in span.

Bridge Slab

gether with the size and spacing of the reinforcing rods will be found in Table 4. It should be noted that the floor slab is given a 2-inch pitch at the center which must be added to the tabulated thickness of the slab. This facilitates the drainage of the roadbed for which drains should be provided as shown in Figure 17.

These bridges are designed to carry a fill of from 8 to 12 inches. The practice of using a concrete floor without a covering of earth or other paving material is not to be recommended. The road material should be carried continously across the bridge or culvert, thus helping to distribute the load and preventing wear and excessive vibration.

Proportions

The concrete for the slab should be proportioned 1 sack of Portland cement, 2 cubic feet of sand and 4 cubic feet of screened gravel or crushed stone. The materials must be selected and mixed as described in section under aggregates on page 11.

Placing of Concrete

In depositing concrete around the steel, great care must be taken, as before stated, to see that the steel is not disarranged and that it is in position as shown by the design. This will be accomplished much more easily if the steel has been thoroughly and carefully wired together.

The concrete should be placed for the full thickness of the slab and in one continuous operation. The depth of concrete below the steel must in all cases be as shown in Table 4 for the various spans.

Figure 18. Concrete Arch Bridge, Marion County, Indiana. 20-foot span; cost $1,500. This bridge is of monolithic concrete construction but marked in imitation of stone masonry.

Arch Bridges

Where the stream banks are steep, giving plenty of head room, and where the soil is clay, gravel or rock, affording a good foundation, the arch type of bridge or culvert is preferable to the flat slab construction. The arch type gives a pleasing artistic appearance, harmonizing agreeably with the character of the country in which this type of bridge construction can be used.

The arch places a heavier load upon its foundation than does the flat slab bridge, but where the proper foundation is secured, this heavier load is an advantage when the effect of the moving loads is considered. The stability of the arch is not affected by an increase in the moving load as the slab bridge would be. However, the least settlement of the abutments endangers the stability of the arch. In all cases the abutments must have a sufficient spread at the base, so that the load on the foundation will not exceed the safe unit load as given in table under "Foundations," page 8.

Forms

Substantial centers or forms must be provided for concrete arches and should be of good quality lumber as previously described. Figure 21 shows in detail, method of constructing the arch form. The ribs as shown in Figure 21 should be spaced every four feet supporting the two-inch by six-inch lagging. These ribs are supported on wooden posts as shown, which must be placed upon a firm foundation. The wedges shown in the figure should be of hardwood and smooth finished so that they may easily be driven without shock, but there must be no danger of them slipping. The safe removal of the centering depends upon the proper driving of these wedges. The spandrel and guard rail forms may be built in place at the same time that the arch ring centering is placed. To prevent the concrete sticking to the forms they should be treated as previously suggested.

When ready to strike the centers, the wedges under the crown of the arch should first be knocked out, leaving those at the springing line until the last. These wedges are essential in order that no unequal strains may be placed upon the arch during the removal of the forms and are therefore the most important item in the construction of the arch centering.

Time to Remove Forms

The arch centers must be left in place until the concrete has hardened thoroughly and the structure is capable of withstanding all loads which may be placed upon it. In no case should these supports be removed in less than 28 days and should remain much longer if the weather has been unfavorable for the hardening of concrete.

Figure 19 shows a design for a plain concrete semi-circular arc bridge varying in span from 10 to 20 feet. The thickness of the arch

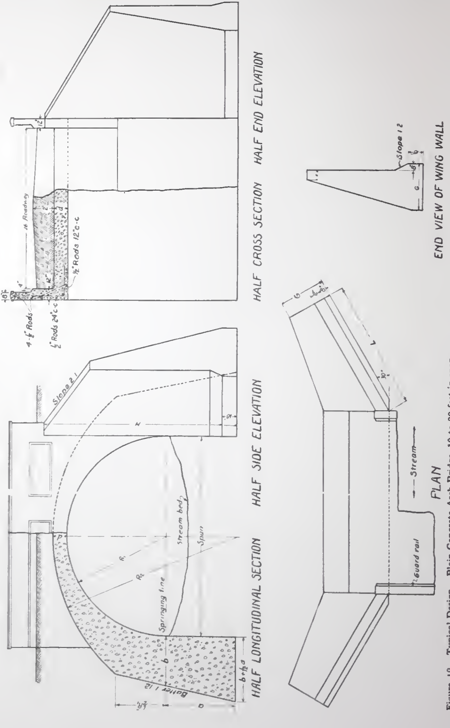


Figure 19. Typical Design. Plain Concrete Arch Bridge, 10 to 20 feet in span.

Conditions Required for Stability ring at the crown and springing line, and amount of reinforcement required for the guard rail is given in Table 5 while Table 6 gives the dimensions of the wing walls and amount of materials required for the various spans. In Table 6, we have assumed a definite value for "a," or the depth of the abutment to the foundation, in order to figure quantities. This value of "a" will be governed entirely by the depth necessary to secure a good foundation, but in going to a greater depth, care must be taken to see that the abutments are stable. In order to secure the proper stability, the width of the base of the abutment must always exceed $\frac{2}{3}$ of the height, that is, the values given in column ("b + 1/12 a") in the table must always be greater than $\frac{2}{3}$"a." If local conditions are such that this does not hold true, the value of "b + 1/12 a" must be increased to comply with this rule.

Proportions for Arch Ring The concrete for the arch ring should be carefully mixed as described in the sections under "Aggregates," page 11 and should be proportioned 1 sack of Portland cement, 2 cubic feet of sand and 4 cubic feet of screened gravel or crushed stone.

The concrete for the arch ring should be placed in one continuous operation. Where it is impossible to place the concrete for the arch in a single day, the arch ring should be divided into either longitudinal or transverse sections such that each section will constitute a day's work. Both methods have been used quite extensively.

Placing of Concrete

However, most engineers believe it to be better practice to build the arch as a series of transverse courses beginning at the springing line. The advantages of this method are that the plane of weakness will be at right

Figure 20. Arch Bridge, Marion County, Indiana. 8-foot span; 2-foot rise; 18-foot roadway. Cost $550.

Table No. 5, Plain Concrete Arch Bridge, 16-Foot Roadway

Span Ft.	Crown d	Spring Line b	R1	R2	b† 1 12 a	Batter	GUARD RAIL				REINFORCEMENT				Diagonal Rods
							HORIZONTAL				VERTICAL				
							No.	Size	Spacing	Length	No.	Size	Spacing	Length	
10	12″	3′– 6″	5′–0″	11′ 9″	The value of "b+1/12 a" must be greater than ⅔a to insure stability of abutment	1:12 in all cases	8	½″	12″	13′	16	½″	24″	5′	26
12	13″	3′ 10″	6′–0″	13′ 6″			8	½″	12″	15′	18	½″	24″	5′	30
14	14″	4′– 1″	7′–0″	14′ 8″			8	½″	12″	18′	22	½″	24″	5′	36
16	15″	4′– 5″	8′–0″	16′ 3″			8	½″	12″	21′	24	½″	24″	5′	40
18	16″	4′– 8″	9′–0″	17′ 8″			8	½″	12″	22′	28	½″	24″	5′	44
20	17″	5′– 0″	10′–0″	18′ 4″			8	½″	12″	25′	30	½″	24″	5′	50

Table No. 6 to Accompany Table No. 5, Plain Concrete Arch Bridge, 16-Foot Roadway Dimensions of Abutments and Amount of Materials

Span	a	H	L	G	CONCRETE		AMOUNT OF MATERIALS		
					Arch Ring and Guard Rail Cu. Yds.	Abutments Cu. Yds.	Cement Bbls.	Stnd Cu. Yds.	Gravel Cu. Yd.
10	To be carried to a firm foundation. Assumed as 3′ to figure quantities.	10′–0″	7′–0″	2′–10″	33.1	31.5	89.0	29.7	59.4
12		11′–0″	8′–0″	3′– 1″	41.3	40.2	112.1	37.5	75.0
14		12′–0″	9′–0″	3′– 4″	48.6	53.6	139.9	47.0	94.0
16		13′–0″	10′–0″	3′– 6″	63.4	61.7	172.2	57.5	115.0
18		14′–6″	11′–6″	3′– 8″	77.3	77.0	212.2	71.0	142.0
20		15′–6″	12′–6″	3′–11″	83.6	85.3	232.0	77.7	155.4

Concrete:
Arch Ring 1:2:4.
Abutments 1:2½:5.

Steel:
Round, Soft Steel Rods

angles to the line of pressure, and that unequal loading and consequent settlement has less tendency to separate one section from another. In building the arch as a series of transverse courses, the concrete should be deposited equally on both sides of the arch. This keeps the loading symmetrical on the forms and prevents unequal settlement. In no instance should a joint be made at the crown.

Since the roadway must not deviate greatly from a horizontal line, a considerable amount of filling is required above the arch ring. This filling should be at least 12 inches in depth at the crown in order to form a cushion and absorb the shock due to passing loads. The standard width of roadway, 16 feet, has been shown in these designs, but this width should, if necessary, be increased to accommodate the traffic.

Earth Fill

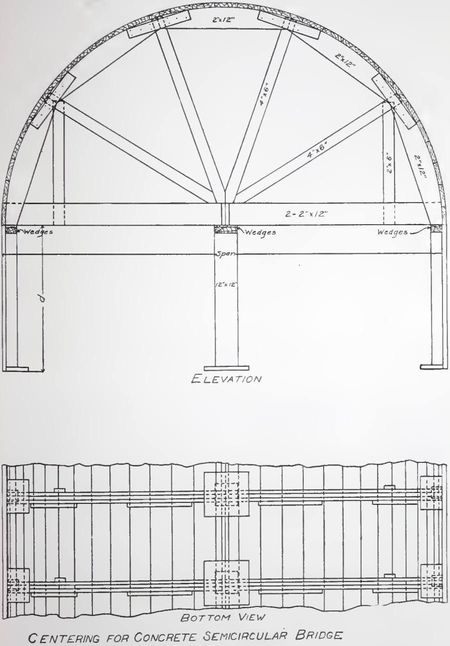


Figure 21. Centering for Concrete Arch Bridges and Culverts.

Culverts

The providing of a satisfactory and economical crossing of the small stream water courses and ditches is not the least of the Highway Commissioner's trouble. Many of these ditches are spanned by wooden or other temporary culverts requiring constant attention and frequently are in a condition to invite accidents. The continual annoyance and expense of repairs can easily be avoided by building concrete culverts.

Angle Across Roadway

The angle at which a culvert crosses the road should be considered carefully. As far as possible, it should be placed in the direction of the flow of the water. In most of the locations, culverts are placed at right angles to the roadway, although the streams seldom cross the roads at right angles. Failure to place culverts across roadways in the direction of the stream flow, often causes clogging which results in washouts thus making repairs necessary.

The length of the culvert will depend upon the width of roadway and the depth of fill on top of the culvert. Where there is a heavy fill on the culvert it must be of sufficient length to accommodate the slope of the fill. The natural slope of any earth fill can generally be taken as $1\frac{1}{2}$ to 1, that is, for every 1 foot in height, the horizontal distance is $1\frac{1}{2}$ feet; therefore, a 10-foot fill with 16-foot roadway would require a culvert 46 feet in length.

Concrete culvert construction is essentially the same as that used for bridges. Likewise the concrete culvert may be built either in arch form or as a simple reinforced flat top concrete box.

Figure 22. Concrete Culvert, Milo, Yates County, New York. Designed by New York Highway Commission. Culvert Head Walls 40 feet long, 16 feet high; opening 5 feet x 6 feet. Built with town labor at a cost of $636.

Box Culvert

In a flat country and under shallow fills, the box culvert has a great advantage over the arch culvert, requiring much less head room and therefore less excavation. The form work for this type of culvert is much simpler and the cost of construction correspondingly lowered.

Forms

The forms for this type of culvert are very simple and no special instructions are necessary. The face of the forms should be made of 2 x 6 lumber, dressed on one side and two edges. The cross section view in Figure 25 shows the supporting bents which should be spaced every three feet and be built of 2 x 4 lumber. In order that the forms may be removed easily, the upper brace is held and fitted in place by wedges. When ready to remove forms, these wedges are knocked out and the supports for the top of the culvert dropped down, thus permitting the easy removal of the forms. The typical design for the forms of the wing walls is shown in Figure 11, page 19.

Floor and Wing Wall

Table 7 gives the dimensions of the wing walls and amount of materials required for abutments and floor of the culvert. Culverts may be built with or without floor according to the stability of the soil and local conditions. The smooth waterway obtained by using concrete floors increases the capacity of the culvert and prevents the clogging of the waterway by drift. This floor will also prevent erosion of the stream bed and the undermining of the foundation. It is advisable to provide joints between the floor and sides of the culvert, thus protecting the floor against cracking should settlement occur. To prevent erosion under floor an apron, as shown in the drawing, should in all cases be carried to a depth equal to the bottom of the footing. The floor is shown as carried out to the end of the wing walls. This improves the smooth waterway and is an added protection to the wing. However, if so desired this floor may be omitted.

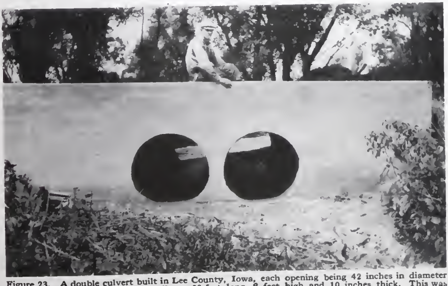


Figure 23. A double culvert built in Lee County, Iowa, each opening being 42 inches in diameter and 20 feet long. The wing walls are 20 feet long, 8 feet high and 10 inches thick. This was built with the Merrillat Culvert Core Company's form at a totol cost of $112.

Table No. 8, Flat Top Culvert, 2-Foot Fill, Computed for 24-Ton Roller

Span	Height	Slab Thickness "d"	SLAB					Side Walls		Materials Per Foot of Length Exclusive of Wing Walls				
			Concrete Below Steel	Reinforcement										
				Tension		Temperature								
				Size	Spacing	Size	Spacing	C	e	Steel lbs.	Concrete Cu. Yds.	Cement Bbls.	Sand Cu. Yds.	Gravel Cu. Yds.
3′–0″	3′–0″	6 ″	1 ″	½″	6 ″	½″	12″	1′– 8″	To extend to firm foundation in all cases. Assumed as 18″ to figure quantities.	8.0	.65	.835	.30	.60
3′–6″	3′–6″	6½″	1 ″	½″	5½″	½″	12″	1′–10″		9.3	.77	.99	.35	.71
4′–0″	4′–0″	7 ″	1 ″	½″	5 ″	½″	12″	2′– 0″		12.2	.89	1.15	.41	.82
4′–6″	4′–6″	7½″	1 ″	½″	4½″	½″	12″	2′–2″		14.6	.97	1.25	.45	.89
5′–0″	5′–0″	8 ″	1 ″	½″	4 ″	½″	12″	2′– 5″		17.3	1.08	1.39	.50	.99
5′–6″	5′–6″	8½″	1 ″	½″	4 ″	½″	12″	2′– 7″		17.3	1.32	1.70	.61	1.21
6′–0″	6′–0″	8½″	1 ″	⅝″	6 ″	⅝″	12″	2′– 9″		20.6	1.49	1.91	.68	1.37
7′–0″	7′–0″	9½″	1¼″	⅝″	5½″	⅝″	12″	3′– 2″		27.0	1.79	2.30	.82	1.65
8′–0″	8′–0″	10 ″	1¼″	⅝″	5 ″	⅝″	12″	3′– 6″		32.0	2.20	2.83	1.01	2.02

Concrete: For Slab 1:2:4. For Side Walls 1:2½:5. Steel: Soft round rods.

Table No. 9, Flat Top Culvert, 6-Foot Fill, Computed for 24-Ton Roller

Span	Height	Slab Thickness "d"	SLAB					Side Walls		Materials Per Foot of Length Exclusive of Wing Walls				
			Concrete Below Steel	Reinforcement										
				Tension		Temperature								
				Size	Spacing	Size	Spacing	C	e	Steel Lbs.	Concrete Cu. Yds.	Cement Bbls.	Sand Cu. Yds.	Gravel Cu. Yds.
3′–0″	3′–0″	6½″	1 ″	½″	5½″	½″	12″	1′– 8″	18″ to figure quantities.	9.3	.66	.85	.39	.60
3′–6″	3′–6″	7 ″	1 ″	½″	5 ″	½″	12″	1′–10″		10.8	.78	1.03	.36	.71
4′–0″	4′–0″	7½″	1 ″	½″	4½″	½″	12″	2′– 0″		13.5	.89	1.15	.41	.82

4′-6″	4′-6″	8 ″	1 ″	½″	4 ″	½″	12″	2′- 2″	To extend to a firm foundation in all cases. Assumed a	15.6	.98	1.27	.45	.90
5′-0″	5′-0″	8½″	1 ″	⅝″	6 ″	⅝″	12″	2′- 5″		17.8	1.09	1.41	.50	1.00
5′-6″	5′-6″	9 ″	1¼″	⅝″	5½″	⅝″	12″	2′- 7″		22.0	1.33	1.72	.61	1.22
6′-0″	6′-0″	9½″	1¼″	⅝″	5 ″	⅝″	12″	2′- 9″		26.2	1.51	1.95	.70	1.39
7′-0″	7′-0″	11 ″	1¼″	⅝″	4½″	⅝″	12″	3′- 2″		32.0	1.83	2.36	.84	1.68
8′-0″	8′-0″	12 ″	1¼″	¾″	6 ″	¾″	12″	3′- 6″		38.0	2.26	2.92	1.04	2.08

Concrete: For Slab 1:2:4. Side Walls 1:2½:5. Steel: Soft round rods.

Table No. 10, Flat Top Culvert, 10-Foot Fill, Computed for 24-Ton Roller

Span	Height	Slab Thickness	Concrete Below Steel	SLAB Reinforcement Tension Size	Tension Spacing	Temperature Size	Temperature Spacing	Side Walls C	Side Walls e	Materials Per Foot of Length Exclusive of Wing Walls: Steel Lbs.	Concrete Cu. Yds.	Cement Bbls.	Sand Cu. Yds.	Gravel Cu. Yds.
3′-0″	3′-6″	6½″	1 ″	½″	5½″	½″	12″	1′- 8″	To extend to a firm foundation in all cases. Assumed as 18″ to figure quantities.	9.3	.66	.85	.30	.61
3′-6″	3′-6″	7 ″	1 ″	½″	5 ″	½″	12″	1′-10″		10.8	.78	1.03	.35	.72
4′-0″	4′-0″	7½″	1 ″	½″	4½″	½″	12″	2′- 0″		13.5	.90	1.16	.41	.83
4′-6″	4′-6″	8½″	1 ″	⅝″	6 ″	⅝″	12″	2′- 2″		15.6	.99	1.28	.45	.91
5′-0″	5′-0″	9 ″	1¼″	⅝″	5½″	⅝″	12″	2′- 5″		20.8	1.11	1.44	.51	1.02
5′-6″	5′-6″	9½″	1¼″	⅝″	5 ″	⅝″	12″	2′- 7″		23.9	1.34	1.73	.62	1.23
6′-0″	6′-0″	10 ″	1¼″	⅝″	5 ″	⅝″	12″	2′- 9″		23.9	1.53	1.98	.70	1.40
7′-0″	7′-0″	11½″	1¼″	⅝″	4 ″	⅝″	12″	3′- 2″		35.4	1.85	2.39	.85	1.70
8′-0″	8′-0″	13 ″	1½″	¾″	5½″	¾″	12″	3′- 6″		41.0	2.29	2.96	1.05	2.10

Concrete: For Slab 1:2:4. For Side Walls 1:2½:5. Steel: Soft round rods,

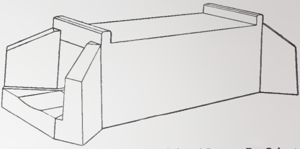


Figure 24. Perspective of Typical Reinforced Concrete Box Culvert shown in Figure 25.

The lengths of the wing walls have been given as equal to the span in every case. This length will undoubtedly be governed to some extent by local conditions, but it will be found that the lengths assumed in Table 7 will be applicable in all ordinary instances.

Culvert Slab

Figure 25 shows a design for a box culvert varying from 3 to 8 feet in span. The thickness of the side walls and top together with amount of steel reinforcing required, can be obtained from Tables 8, 9, 10. These tables also give the amount of materials per linear foot of culvert. Where the culvert is to be placed at the bottom of a fill, it must be designed to sustain the additional load due to the weight of the earth fill, and these tables have, therefore, been figured for two, six and ten foot fills. The tables appear on pages 36 and 37.

Concrete for the culvert slab should be proportioned 1:2:4, that for the sides, wing walls and floor should be 1:2½:5.

Table No. 7 to be Used with Tables Nos. 8, 9 and 10. Dimensions for Wing Walls—Flat Top Culvert

Span	Height = Span + Floor Thickness	L = Span	G	Depth of Apron	Amount of Materials, Including Apron, Guard Rail, and Floor Between Wing Walls			
					Concrete Cu. Yds.	Cement Bbls.	Sand Cu. Yds.	Gravel Cu. Yds.
3'-0"	3'- 6½"	3'-0"	1'- 8"	Minimum depths 18". Should be carried to bottom of footings in all cases.	3.5	4.7	1.6	3.2
3'-6"	4'- 1 "	3'-6"	1'-10"		4.3	5.4	2.0	4.0
4'-0"	4'- 7½"	4'-0"	2'- 0"		5.8	7.2	2.7	5.4
4'-6"	5'- 2½"	4'-6"	2'- 0"		7.1	8.9	3.3	6.6
5'-0"	5'- 9 "	5'-0"	2'- 3"		8.6	10.7	4 0	8.0
5'-6"	6'- 3½"	5'-6"	2'- 3"		10.4	13.0	4.8	9.6
6'-0"	6'-10 "	6'-0"	2'- 6"		12.8	16.0	5.9	11.8
7'-0"	7'-11½"	7'-0"	2'- 9"		17.4	21.8	8.0	16.0
8'-0"	9'- 1 "	8'-0"	3'- 0"		25 6	32.0	11 8	23.6

Concrete:
1:2½:5

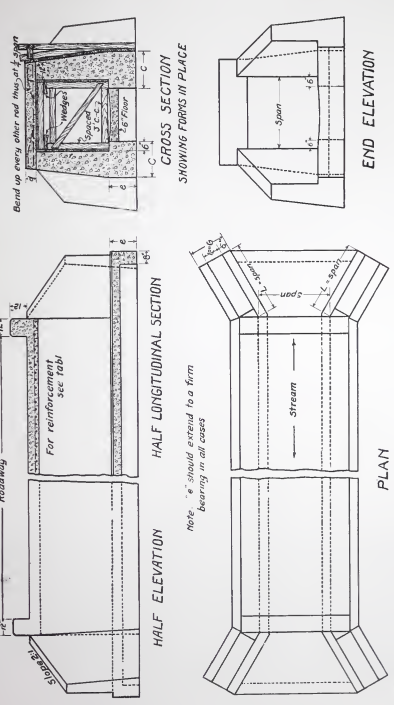


Figure 25. Typical Design. Reinforced Box Culvert, 3 to 10 feet in span.

When the area of waterway required is small, that is, under 36 inches in diameter, it is more economical to build a concrete pipe culvert. No culvert of this class should be constructed having a smaller opening than 15 inches. These culverts are not complete without head walls as shown in the other designs.

Collapsible Wood Forms for Circular Culvert

Figure 27 shows an adjustable, collapsible wood form which can be very economically used for the construction of culverts from 18 in. to 48 in. in diameter. It was originally designed by F. H. Meliza, Farmer City, Ill., and was mentioned in the Illinois Highway Commission reports for 1907 and in a bulletin on highway improvement by W. S. Gearhart, Highway Engineer of Kansas, which was issued by the Kansas State Agricultural College.

This form is constructed of two by four's beveled and strung on wires as shown in the figure. The number of staves to be used, varying with the size of the culvert are placed side by side with a wire drawn through each end of the stave as shown. The form is then rolled around a circular head size of the proposed culvert and wire bands are tied tightly around it on the outside. Wedges are then driven as shown in Figure 27 to hold the staves firmly in position. After the culvert has been built the wedges are removed, and the circular heads knocked in; the staves will then collapse and are easily removed. This form can be used over and over again and Mr. Gearheart states that its cost should not exceed $15.00 or $20.00.

Figure 26. Reinforced Concrete Arch Bridge, Iroquois, South Dakota, 20-foot Span, 18-foot roadway. Designed by Missouri Valley Engineering Company, R. S. Warner, Contractor.

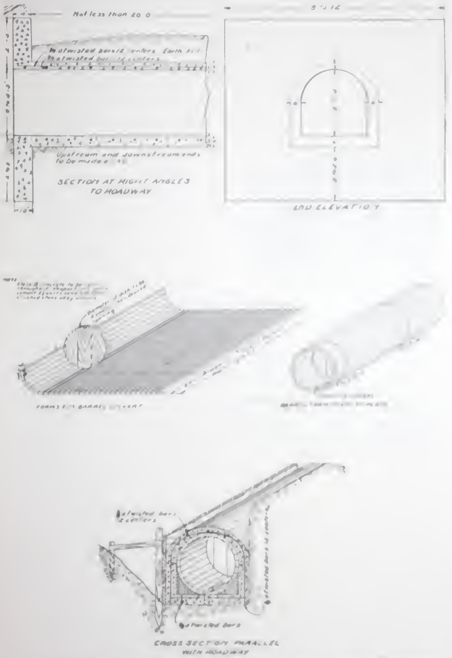


Figure 27. Plan for a collapsible, adjustable wood form for the construction of concrete culverts from 18 inches to 48 inches in diameter.

Plain Arch Culverts

The construction of arch culverts is essentially the same as for arch bridges. The arch culvert has the same advantages and disadvantages, when compared with the box culvert, as has the arch bridge when compared with the flat slab bridge. This type can be used only where there is plenty of head room or under a heavy fill; and where a suitable foundation can be obtained.

Figure 28. Plain Concrete Arch, 6-foot span, McLean Co., Illinois.

Forms

The forms for the arch culvert are similar to those required for an arch bridge and therefore, the centering as shown in Figure 21 is also applicable to the arch culverts. In the smaller spans it will not be necessary to provide wedges as shown for the larger sizes. However, care must be taken in striking the centers to see that no unusual strains are placed on the arch ring. The concrete for the footings and floor in the stream bed should be deposited first and the forms for the arch and sides can be erected on this concrete. The forms for the wing walls should be constructed as shown in detail in Figure 11, page 19.

Tables of Dimension

Figure 29 shows a design for plain arch culverts from 3 to 10 feet in diameter. The thickness of arch at crown and springing line for the various spans together with amount of materials required per linear foot of culvert are given in Table 11. Table 12 gives the dimensions of the wing walls and amount of materials required for abutments and floor of the culvert between the wing walls.

Conditions Required for Stability

The distance "h" or the height of the sides of the culvert from the top of the footing to the springing line, has been given a definite value in the tables. This value of "h" can, however, be governed to a certain extent by the area of waterway required, and may be varied to suit conditions. This variation in the value of "h" is limited for the reason that "h" must never exceed $1\frac{1}{2}$ times the

thickness of the side walls at the top of the footing. If "h" exceeds this limit in height, the stability of the structure will be endangered. The sides of the culvert have been given a batter of 1 in 12 and a spread footing provided. This footing should be carried to a firm foundation at all times.

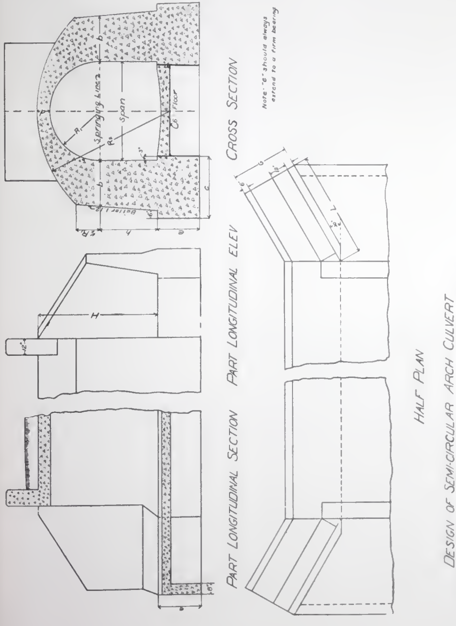


Figure 29. Typical Design. Plain Concrete Arch Culvert, 3 to 10 feet in span.

The concrete for an arch culvert should be placed in the same way and manner as described for an arch bridge. The arch ring should be deposited in one day where possible. If impossible to complete the arch

Table No. 11, Plain Concrete Arch Culvert

Span	Crown d	Springing Line b	R1	h	C	e	Materials Per Foot at Length			
							Concrete Cu. Yds.	Cement Bbls.	Sand Cu. Yds.	Gravel Cu. Yds.
3′	6″	2′– 5″	1′–6″	2′–0″	3′– 4″	To extend to a firm foundation in all cases. Assumed as 18″ to figure quantities.	1.13	1.5	.52	1.04
3′–6″	6″	2′– 7″	1′–9″	2′–0″	3′– 6″		1.27	1.7	.58	1.16
4′–0″	6½″	2′– 8″	2′–0″	2′–6″	3′– 8″		1.41	1.8	.65	1.30
4′–6″	7 ″	2′– 8″	2′–3″	2′–6″	3′– 8″		1.50	2.0	.69	1.38
5′–0″	7½″	2′– 9″	2′–6″	3′–0″	3′– 9″		1.59	2.1	.73	1.46
5′–6″	8 ″	2′– 9″	2′–9″	3′–0″	3′– 9″		1.71	2.3	.79	1.58
6′–0″	8½″	2′–10″	3′–0″	3′–0″	3′–10″		1.93	2.6	89	1.78
7′–0″	9 ″	3′– 0″	3′–6″	3′–6″	4′– 0″		2.32	3.1	1.07	2.14
8′–0″	10 ″	3′– 2″	4′–0″	4′–0″	4′– 3″		2.72	3.7	1.25	2.50

Concrete:
Arch Ring 1:2:4.
Abutments 1:2½:5.

in one day, it should be divided into transverse sections as previously described and each section taken as a day's work. In no case should a joint be made at the crown. The concrete for the arch culvert should be proportioned same as that for the arch bridge.

Table No. 11 to Accompany Table No. 12, Plain Concrete Arch Culvert Dimensions of Wing Walls and Amount of Materials Including Guard Rails Floor and Apron

Span	Height H	L	G	Concrete Cu. Yds.	Cement Bbls.	Sand Cu. Yds.	Gravel Cu. Yds.
3′	4′– 0″	3′–0″	2′–0″	3.8	4.72	1.75	3.50
3′–6″	4′– 3″	3′–6″	2′–0″	4.2	5.21	1.93	3.86
4′–0″	5′– 0″	4′–0″	2′–2″	6.9	8.55	3.18	6.36
4′–6″	5′– 7″	4′–6″	2′–4″	8.8	10.91	4.05	8.10
5′–0″	6′– 1″	4′–6″	2′–6″	10.2	12.64	4.69	9.38
5′–6″	6′– 5″	5′–0″	2′–7″	11.1	13.77	5.11	10.22
6′–0″	6′– 8″	5′–0″	2′–9″	12.8	15.87	5.88	11.76
7′–0″	7′– 9″	5′–6″	3′–0″	14.3	17.73	6.57	13.15
8′–0″	8′–10″	6′–0″	3′–5″	18.3	22.70	8.43	16.86

Figure 30. Concrete Arch Culvert, Marion Co., Indiana. 6-foot span; 3½-foot rise; 18-foot roadway. Cost $700. This bridge is of monolithic construction marked in block form.

Standard Plans of State Highway Commissions

On the following pages, we show bridge and culvert designs used by several of the State Highway Commissions. These designs are standard for the different states and indicate the best engineering practice in this line.

The variation in thickness of slab and amount of reinforcement in the different designs is due to different assumptions as to loading and the strength of concrete in compression. The variation in the designs indicates the variations in traffic conditions in the different states and that the State Engineers have designed the bridges to accommodate local traffic.

The larger arch bridges which are shown are all of the reinforced type. Where the cost of materials is high, this type of arch design is probably more economical than a plain concrete arch but should never be undertaken except by an experienced man. For this reason no reinforced concrete arch designs are shown.

On the other hand, the plain concrete arch is very simple of construction after the forms have been placed in position, and a man with but little experience in this class of concrete work can undertake the construction.

Figure 31 Small bridge over Dixie Run, near Hooversville, Pa.

Illinois

Figure 32 shows the standard design of the Illinois Highway Commission, A. N. Johnson, State Highway Engineer, for a flat slab bridge of 20-foot span. The following table gives quantity and size of steel reinforcement required. Because of the low clearance or head room which is obtained over the streams in Illinois, the Highway Commission has adopted the flat slab and through girder types of concrete bridges entirely.

Letter	No.	Size	Length
A	....	1 "	25′ 0″
B	20	½″	....
C	6	½″	21′ 8″
D	40	½″	4′ 8″

Note:—

Exposed edges of girders and rails to be beveled with ¾-inch triangular molding.

Where grooved panels are shown the same to be made by ¾-inch triangular molding.

Macadam wearing surface not to be included in contract.

Concrete to be proportioned 1:2½:4.

All steel reinforcing bars must be mild or medium steel rolled from billets.

No rerolled material or high carbon steel will be permitted.

All bars must be obtained in the full lengths indicated in bill of material.

Kansas

Figure 33 is a design for a 15-foot span, flat slab bridge issued by the Office of State Engineer, Manhattan, Kansas, W. S. Gearhart, State Engineer. Amount and size of steel reinforcement required is given in the following table.

Bill of Material

Letter	No.	Size	Length
A	16	¾″ sq.	16′ 9″
A1	16	¾″ sq.	17′ 6″
A2	15	¾″ sq.	17′ 6″
B	15	½″ sq.	26′ 0″
C	6	½″ sq.	16′ 9″
D	24	¾″ sq.	5′ 0″

Concrete to be used in floor and girders, proportioned 1:2:4. Concrete to be used in wing walls and abutments proportioned 1:3:5. A ¾-inch triangular molding shall be used to bevel all exposed corners of the girders, guard rails and wing walls.

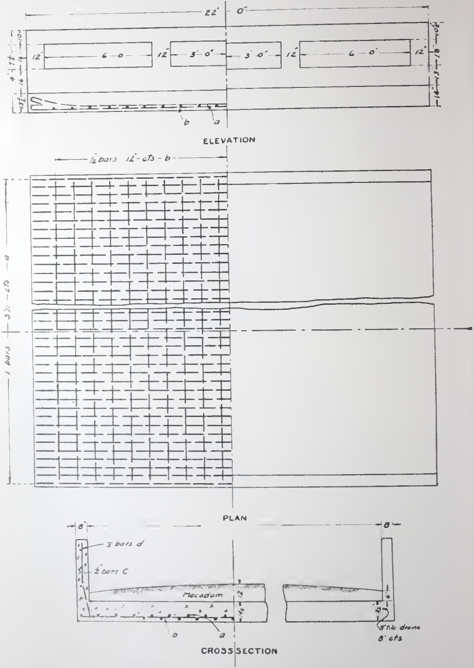


Figure 32. Concrete Superstructure of 20-foot span, 12 to 20-foot roadway. Designed by the Illinois Highway Commission.

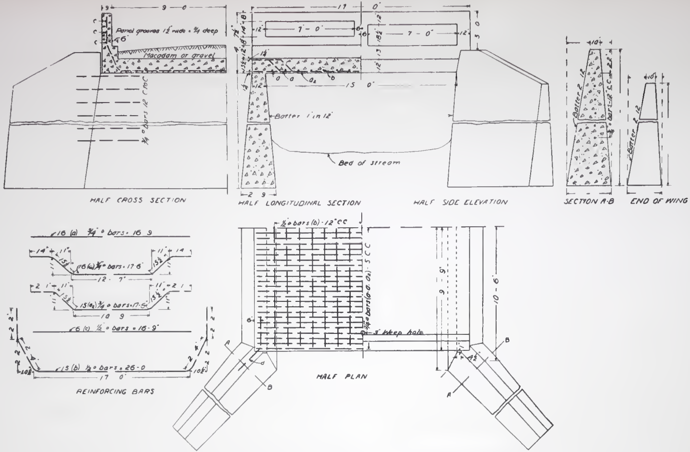


Figure 33. Concrete bridge of 15-foot span at Manhattan, Kans. Designed in the office of the State Engineer at the Kansas State Agriculture College.

New York

Figure 34 is the standard design of the State of New York, Department of Highways, for flat slab bridges 10 feet to 20 feet in span. John A. Bensel, State Engineer. The table on the following page gives slab thickness and amount of reinforcement required for the various spans.

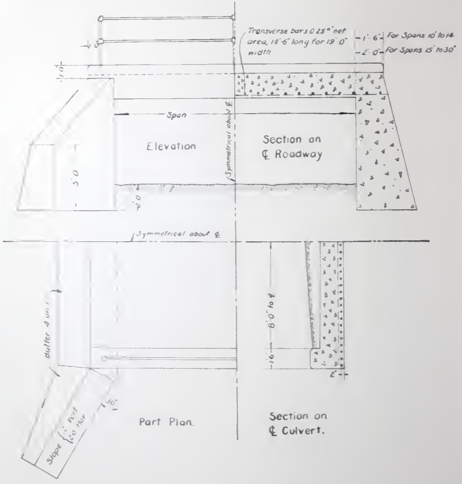


Figure 34. Standard culvert with rod reinforcement of 10 and 20-foot span. Designed by the Department of Highways of the State of New York.

Clear Span	Thickness of Slab	Cross Section of Bars	Weight per Foot of Bars	Length of Each Bar	Distance to Center of Bars
10′	12″	.56″	1.91 lbs.	13′ 0″	6½″
11′	12″	.56″	1.91 lbs.	14′ 0″	6½″
12′	13″	.56″	1.91 lbs.	13′ 0″	6 ″
13′	13″	.56″	1.91 lbs.	16′ 0″	5½″
14′	14″	.56″	1.91 lbs.	17′ 0″	5½″
15′	14″	.56″	1.91 lbs.	19′ 0″	5 ″
16′	15″	.56″	1.91 lbs.	20′ 0″	4½″
17′	15″	.56″	1.91 lbs.	21′ 0″	4½″
18′	16″	.56″	1.91 lbs.	22′ 0″	4½″
19′	17″	.56″	1.91 lbs.	23′ 0″	4 ″
20′	18″	.77″	2.60 lbs.	24′ 0″	5 ″

All rods to have a deformed cross-section.
Round all exposed edges to a 1½-inch radius.
2nd class concrete in slab.
3rd class concrete in wing walls and abutments.

Massachusetts

Figure 35 shows standard design for reinforced concrete box culverts used by the Massachusetts Highway Commission, A. W. Dean, Chief Engineer. This figure shows the designs for box culverts 1½ feet by 1½ feet; 2 feet by 3 feet; 3 feet by 4 feet and 4 feet by 5 feet. The amount of concrete and reinforcement required is given in each case.

Ohio

The design shown in Figure 36 is a Standard Concrete Bridge des gn of 9-foot span, 20-foot roadway, used by the Ohio State Highway Department. James R. Marker, State Highway Commissioner, Clyde T. Morris, Bridge Engineer. The following table gives the estimated quantities of steel and concrete for the superstructure.

All concrete work shall conform to the "General Specifications for concrete and reinforced concrete structures" of the State Highway Department.

Estimated Quantities for Superstructures

Concrete 1:2:4	13 1/10 cu. yds.
Steel—	
44 pieces ¾″ sq. t w. 11′ 6″ long	975 lbs.
3 pieces ⅜″ sq. t w. 21′ 6″ long	95 lbs.
Total Steel	1070 lbs.
Wire Netting, No. 9, 4″ to 6″ mesh	240 sq. ft.

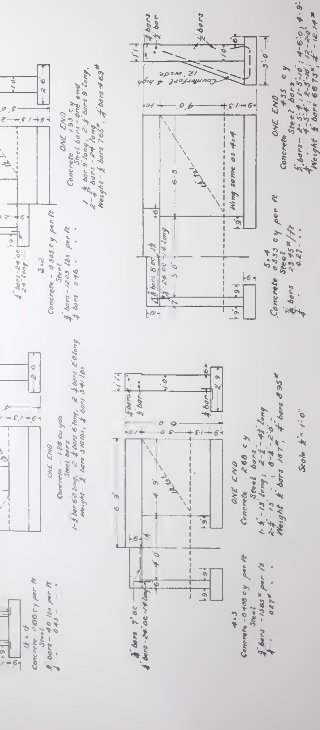


Figure 35. Standard Box Culvert Designs. Massachusetts Highway Commission.

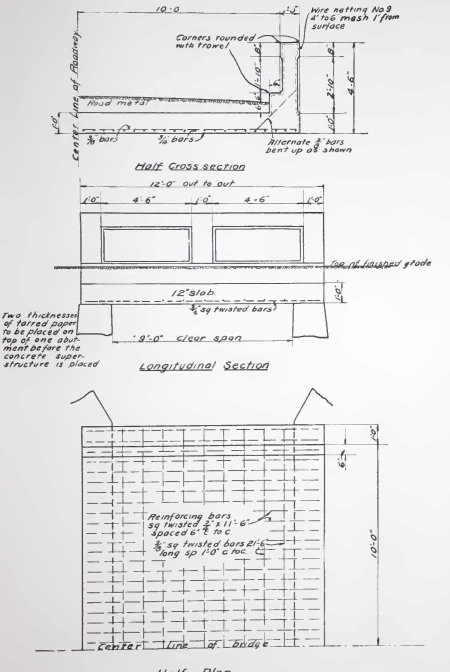


Figure 36. Standard concrete bridge of 9-foot span and 20-foot roadway. Designed by the Ohio State Highway Department. (Class "C" loading.)

Virginia

Figure 37 is the typical design for reinforced concrete slabs for highway culverts used by the Virginia State Highway Commission, P. St. J. Wilson, Highway Commissioner. Table showing amount of concrete and steel reinforcement for the various spans is given on the following page.

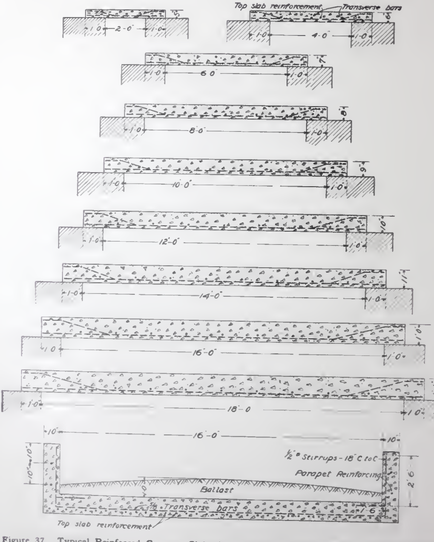


Figure 37. Typical Reinforced Concrete Slabs for Highway Culverts, Office of State Highway Commission, Richmond, Va.

Table Showing Reinforcement of the Virginia State Highway Commission's Standard Culvert Slabs

Span	Top Slab Reinforcement				Transverse Reinforcement			Parapet Reinforcement				Stirrups				Quantities	
	Size	Space	Length	No.	Size	Length	No.	Size	Space	Length	No.	Size	Space	Length	No.	Concrete Cu. Yds.	Steel Lbs.
2	5/8″	8″	4′-6″	26	5/8″	21′-3″	2	1/2″	10″	9′-6″	4	1/2″	18″	4′-0″	6	1.70	247.5
4	3/4″	8″	6′-6″	26	5/8″	21′-3″	3	1/2″	10″	6′-6″	4	1/2″	18″	4′-0″	8	2.88	456.8
6	3/4″	6″	8′-6″	35	5/8″	21′-3″	4	1/2″	10″	8′-6″	4	1/2″	18″	4′-0″	10	4.26	744 0
8	7/8″	7″	10′-6″	30	5/8″	21′-3″	5	1/2″	10″	10′-6″	4	1/2″	18″	4′-0″	12	5.99	1036.6
10	7/8″	6″	12′-6″	35	5/8″	21′-3″	6	1/2″	10″	12′-6″	4	1/2″	18″	4′-0″	16	7.73	1403.7
12	7/8″	6″	14′-6″	35	5/8″	21′-3″	7	1/2″	10″	14′-6″	4	1/2″	18″	4′-0″	18	9.75	1627.5
14	1 ″	7″	16′-6″	30	5/8″	21′-3″	8	1/2″	10″	16′-6″	4	1/2″	18″	4′-0″	20	11.99	2032.9
16	1 ″	6″	18′-6″	35	5/8″	21′-3″	9	1/2″	10″	18′-6″	4	1/2″	18″	4′-0″	24	14.51	2600.0
18	1 ″	6″	20′-6″	35	5/8″	21′-3″	10	1/2″	10″	20′-6″	4	1/2″	18″	4′-0″	26	17 25	2889.8
20	1 1/8″	6″	22′-6″	35	5/8″	21′-3″	11	1/2″	10″	22′-6″	4	1/2″	18″	4′-0″	30	20.22	3875.2

Note—Twenty feet clear span not shown. Thickness of slab 14 inches. Sizes and Sections for square bars shown in table.

All concrete 1 part No. 1 Portland cement, 2 parts sharp, clean sand and 4 parts of broken stone, sizes 1/4″ to 1 inch. Reinforcement of structural steel square bars of sizes shown. Every alternate bar bent up as shown. All bars except Stirrups and Transverse bars to be bent 3-inch at each end in addition to bending of alternate bars. All Transverse Bars to be bent up 2 feet 5 inches at each end and into Parapet as shown. Specifications Virginia State Highway Commission, 1909. Capacity: 12-Ton Roller.

Wisconsin

Figure 39 shows the standard design used by the Wisconsin Highway Commission. A. R. Hirst, Acting State Engineer; M. W. Torkelson, Bridge Engineer. The amount of steel reinforcement required is shown in figure 40.

Concrete—

Superstructure—1:2:4 mixture requires 17.3 cubic yards.
Substructure—1:3:6 mixture requires 34.0 cubic yards.
For each vertical foot of change in height of substructure, add or subtract 3.1 cubic yards.

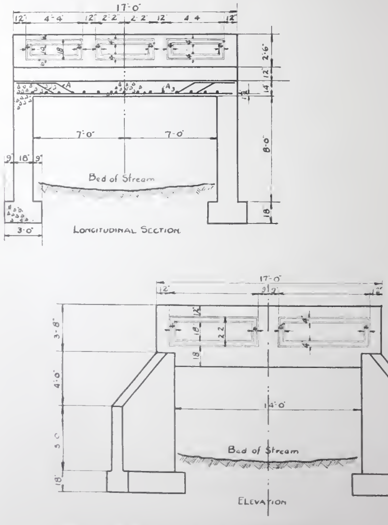


Figure 38. Section and elevation of bridge shown in Figure 40.

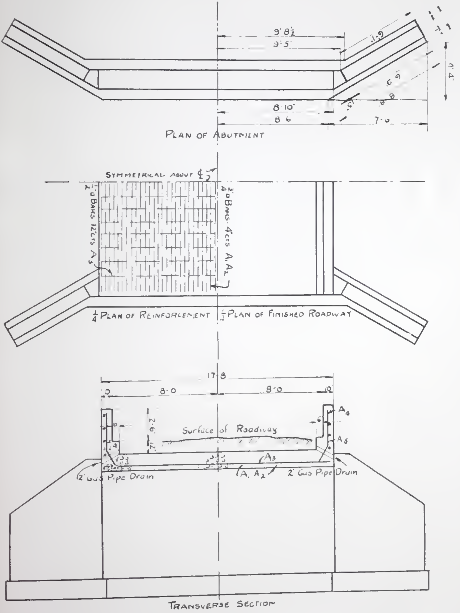


Figure 39. Concrete Bridge of 14-foot span and 16-foot roadway. Designed by the Wisconsin State Highway Commission.

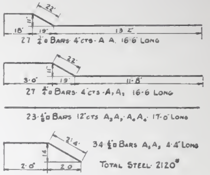


Figure 40. Bill of Material for Steel for Bridge shown in Figure 40.

Illinois

Figure 41 shows the design for plain concrete abutments used by the Illinois Highway Commission. This type of substructure is used where the height of abutment is not great or where plain concrete is desirable because of the cheapness of materials. It will be noted that the dimensions of the wing walls have been omitted in this design. This is for

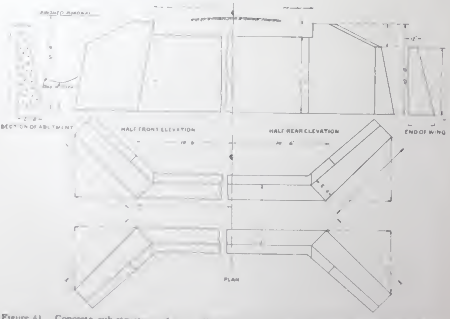


Figure 41. Concrete sub-structure of over all height of 10½ feet. Designed by the Illinois State Highway Commission.

the reason that the height and length of the wing walls is so influenced by the character of the banks of the stream that these dimensions will vary for each structure.

Note—

Use two thicknesses of building paper between adjacent surfaces of substructure and superstructure.

All exposed edges of wings to be beveled with ¾-inch triangular molding.

Concrete to be proportioned 1:3:5.

Place 3-inch tile drains in abutment walls 1 foot above ground line at abutment.

Iowa (Arch)

Figure 43 gives the standard design for 20-ft. span, 8-ft. rise, reinforced concrete arch culvert used by the Iowa Highway Commission, T. H. McDonald, State Highway Engineer. The wing walls in this design are shown parallel to the axis of the roadway and are reinforced. This arch is not semi-circular as it is only given an 8-ft. rise in 20-ft. span.

Design may be used with or without pavement, apron wall to be constructed in either case. Transverse arch bars to be fastened with 1½ × ¼ in. lattice bars as shown.

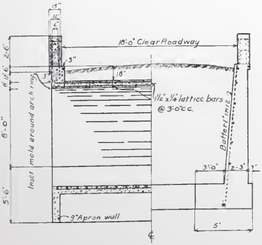
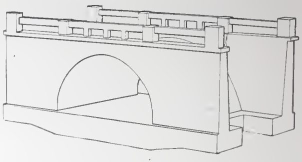
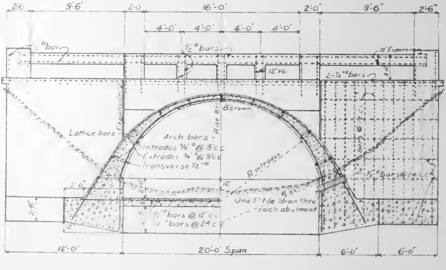
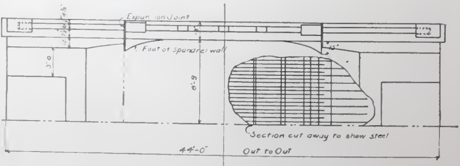


Figure 42. Section and End View of Bridge shown in Figure 43.





GENERAL ELEVATION



HALF PLAN

Figure 43. Standard Design. 20-foot span; 8-foot rise; Reinforced Concrete. Iowa Highway Commission.

Minnesota (Arch)

Figure 44 is the standard design for plain concrete arch culverts used by the Minnesota State Highway Commission, George W. Cooley, State Engineer. The following table gives the dimensions for the various spans.

Table of Dimensions for Plain Concrete Culverts Concrete

Sizes 2 x 2 Feet, to 4 x 4 Feet

W	H	A	B	C	D	E	F	I	K	M	N	T
2′ 0″	2′ 0″	1′ 0″	0′ 8½″	1′ 2″	5′ 5″	3′ 0″	1′ 2″	0′ 6″	0′ 6″	0′ 8″	0′ 8″	0′ 8″
2′ 0″	2′ 6″	1′ 0″	0′ 8½″	1′ 2″	5′ 3″	3′ 6″	1′ 4″	0′ 6″	0′ 7″	0′ 8″	0′ 8″	0′ 8″
2′ 6″	2′ 6″	1′ 2″	0′ 9½″	1′ 3″	6′ 5″	3′ 6″	1′ 5″	0′ 6″	0′ 7″	0′ 8″	0′ 8″	0′ 9″
2′ 6″	3′ 0″	1′ 2″	0′ 9½″	1′ 3″	6′ 5″	4′ 0″	1′ 7″	0′ 6″	0′ 8″	0′ 8″	1′ 0″	0′ 9″
3′ 0″	3′ 0″	1′ 4″	0′ 10½″	1′ 4″	7′ 5″	4′ 0″	1′ 8″	0′ 7″	0′ 8″	1′ 2″	1′ 0″	0′ 10″
3′ 0″	3′ 6″	1′ 4″	0′ 10½″	1′ 4″	7′ 5″	4′ 6″	1′ 10″	0′ 7″	0′ 9″	1′ 2″	1′ 0″	0′ 10″
3′ 6″	3′ 6″	1′ 6″	0′ 11½″	1′ 5″	8′ 5″	4′ 6″	1′ 11″	0′ 7″	0′ 9″	1′ 2″	1′ 4″	0′ 11″
3′ 6″	4′ 0″	1′ 6″	0′ 11½″	1′ 5″	8′ 5″	5′ 0″	2′ 1″	0′ 7″	0′ 10″	1′ 2″	1′ 2″	0′ 11″
4′ 0″	4′ 0″	1′ 8″	1′ 0½″	1′ 6″	9′ 5″	5′ 0″	2′ 2″	0′ 8″	0′ 10″	1′ 2″	1′ 8″	1′ 0″

Note—

Dimensions indicated by figure are constant for all sizes. Length will vary with width of roadway and depth of fill. Where ground is soft, the gutter at the outlet should be paved

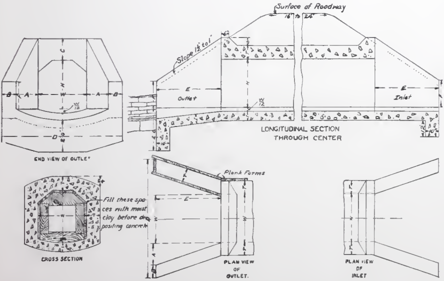


Figure 44. Concrete Culverts designed by the Minnesota State Highway Commission.

with concrete or well-shaped cobble or other suitable stone as indicated on longitudinal section.

Concrete

Concrete shall consist of one part by volume of Portland Cement, 2½ parts of clean, sharp sand and 5 parts of 2-inch broken stone or screened gravel containing pebbles from ¼-inch to 2-inch in size, or may be of 1 part by volume of Portland Cement and 5½ parts of selected pit gravel approved by County Superintendent of Highways.

U. S. Department of Public Roads (Arch)

Figure 45 shows the standard design for a Plain Concrete Arch Culvert, Span 6 foot, issued by the Office of Public Roads, U. S. Department of Agriculture Bulletin No. 39. It should be noted that this culvert is designed for a 24-foot roadway. This is the standard width used in all designs of the Office of Public Roads. The wing walls on the up-stream end of the culvert are placed at an angle of 30° to the direction of the stream flow, while those on the down stream face are placed at right angles to the roadway.

The following amount of materials will be required for this culvert.

Quantities Required

Concrete, arch and parapets (1:2:4) 12.9 cu. yds.
Concrete, side, end and wing walls (1:2½:5) 39.8 cu. yds.
Concrete, footings (1:3:6) 20.1 cu. yds.

Total Quantities

102 barrels cement.
33 cu. yds. Sand.
66 cu. yds. Stone or Gravel.

Oklahoma (Arch)

Figure 46 is the standard design of the Oklahoma State Highway Department, W. R. Goit, Engineer, for a reinforced concrete arch culvert of 15-foot span. This design shows a rise of six feet from the springing line to the crown. The use of reinforcing steel in a concrete arch permits the use of a much flatter arch than can be designed of plain concrete, and does not require as much head room as the semi-circular arch.

The following table gives amount of concrete and reinforcing steel required for this design.

Quantities of Materials for 16-foot Roadway:
Concrete, 38 cubic yards.
Steel, 1709 lbs. ½-inch square bars twisted.
For each additional 2 feet in width:
Concrete, 2 cu. yds. + 6 cu. ft.
Steel, 126 lbs.

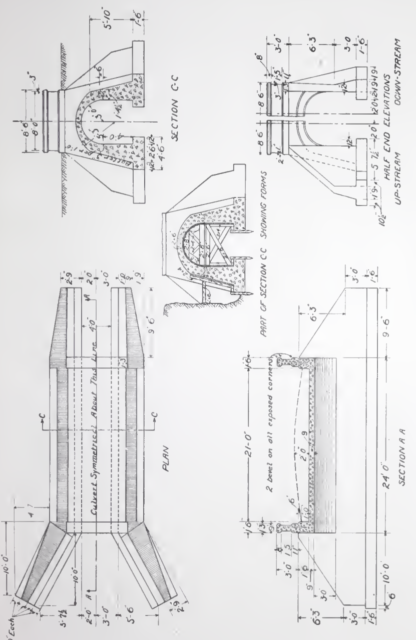


Figure 45. Plan for a Plain Concrete Arch Culvert. Span 6 feet. Office of Public Roads. U. S. Department of Agriculture.

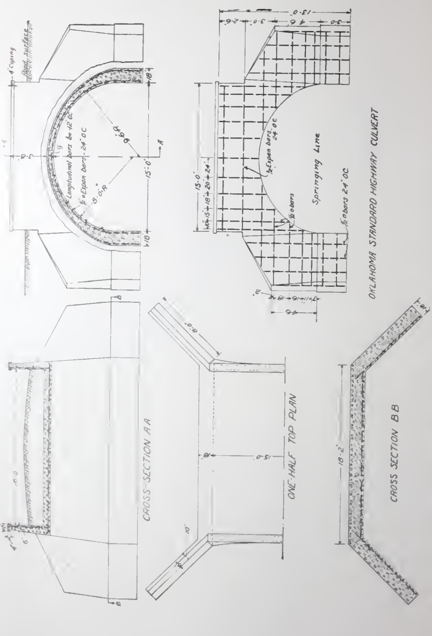


Figure 46. Standard Highway Culvert, Reinforced Concrete 15-foot Arch. Oklahoma State Highway.

Commercial Culvert Forms

There are a number of collapsible steel forms on the market for the construction of both plain and reinforced concrete culverts which are proving satisfactory. The use of a steel form for the construction of one or two small culverts is not an economical proposition, but where the country or township has a number of small culverts to build, they would probably find it advisable to invest in a set of steel forms. In the following paragraphs we give a brief description of several of the leading commercial culvert forms.

Blaw Steel Centering Co.

The Blaw Steel Construction Co., Westinghouse Building, Pittsburgh, Pa., manufactures an adjustable steel form for semi-circular arch culverts having a radius from 9 in. to 24 in. and a height of side wall of 1 ft. 3 in. This form comes in lengths from 6 ft. to 16 ft. and is easily adjustable to all the intermediate sizes. They also have forms for box culverts. These forms come in five foot sections which are made in three sizes, being capable of a large range of adjustment. No. 1 adjusts from 24 in. by 24 in. to 32 in. by 32 in.; No. 2 from 30 in. by 30 in. to 38 in. by 38 in; and No. 3 from 36 in. by 36 in. to 44 in. by 44 in. This company also manufactures steel lagging which can be used in the construction of large box culverts, retaining walls, etc., and collapsible arch ribs which are used with wooden lagging on arches 20 ft. and larger in span.

Figure 47. Luten type reinforced concrete bridge near Holliday's Cove, West Virginia, which withstood unusual flood conditions, the only damage being to the concrete railing which was shattered by the debris carried by the flood.

Concrete Form and Engine Co.

The Concrete Form and Engine Co. of Detroit, Michigan, manufactures a collapsible steel form which is not adjustable. It comes in sections 10 feet long and in 10 sizes, having a semi-circular top ranging 6 in. to 37 in. in radius, while the height of the sides ranges from 9 in. to 42 inches. The tops and sides are all interchangeable which permits some range of adjustment. Two sections make a complete form and consist of the semi-circular tops, sides and end plates.

The side plates are held in position by swinging braces, so that when locked the sides are immovable. The top, setting between the two side plates, is held in position by arms attached to the side plates by bolts which allow the arms to be lowered by pulling the draw rods attached to them. End plates are made which fasten to the top and side plates by keys so that they may be removed easily.

The forms are made of 16-gauge galvanized steel covering, reinforced by steel ribs on the inside and the working parts are comparatively simple and easy to operate.

Dooley Steel Center Co.

The Dooley Steel Center Co. of Fond du Lac, Wisconsin, manufactures a form consisting of a one-piece circular shell with turnbuckle ribs and a wire gauge ring. It is manufactured in 15 sizes from 18 in. in diameter to 72 in. in diameter, five of the larger sizes being adjustable to a slight extent. The forms are made in 10-foot sections which can be telescoped one within the other, giving forms of any length. This form is not provided with end or side plates but has the advantage of being extremely simple in construction. To use this form, it is necessary first to fill the bottom of the proposed culvert trench with concrete. The form is then set on this fresh concrete and the concrete for the top and sides deposited around the form.

Figure 48. Concrete Culvert, McLean County, Illinois. 42-inch diameter; 20 feet in length. Built by Township Commissioners in 10 hours over Merrillat culvert forms. Cost, exclusive of form, $62.50.

Kelly Mfg. Co.

The Kelly Manufacturing Co., of Waterloo, Iowa, manufactures a collapsible steel form for culverts 13 in. to 48 in. in diameter and 16, 18, 20 and 24 feet in length. It is a circular culvert form similar to the one described above, but is provided with end plates for the construction of the end walls. It is necessary to deposit concrete first in the bottom of the trench and then set the form on this fresh concrete. The form is easily collapsed by drawing the tie rod and all the working parts are of very simple construction. This mold is manufactured by the above company but is placed on the market through their selling agents, the Waterloo Cement Machinery Corporation, Waterloo, Iowa.

Merrillat Culvert Core Co.

The Merrillat Culvert Core Co., of Winfield, Iowa, manufactures a collapsible steel form adjustable to any size from 20 in. to 48 in. in diameter. This form consists of a circular core adjusted by ribs radiating from a steel center shaft, and controlled by a hand wheel at one end. The cores are made in 8 and 10 foot lengths and are used in sets of two. With this form, the concrete must first be placed in the bottom of the trench and the form then placed upon it, after which the concrete for the sides and top of the culvert is deposited around the core.

There are no end plates with this form and its great advantage lies in the fact that it is so easily adjusted to any size. The form is substantially and durably built; all the operating parts are of malleable iron and every part that comes in contact with the concrete is heavily galvanized. This form is also equipped with trucks which make it easily portable. The Merrillat Company also manufactures an adjustable arch form for arches from 6 to 12 feet in span.

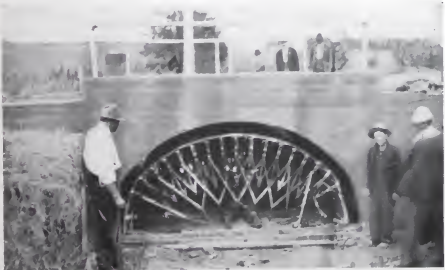


Figure 49. This bridge was built in Adams County, Nebr., at a total cost of $225, including material, labor and freight on gravel, which was shipped in by rail. The span is 12 feet, the roadway 16 feet and the wings, 7 feet long. The form used in this case is adjustable for spans from 6 to 12 feet and can be set at any angle across the road.

The Merrillat Co. also manufacture an adjustable arch form for arches ranging from 6 to 12 feet in span and in units of 4 feet in length so that bridges may be built of any length by using additional sections. This form is also adjustable at any angle across the road and may be set up in a few hours and after the concrete has set can be removed in a few minutes. The form is in the shape of a half ellipse but the curve may be adjusted to suit the user.

Township Supply Co.

The Township Supply Co., of St. Louis, Mo., manufactures an adjustable circular steel form which comes in two sizes; one can be adjusted from 14 in. to 24 in. in diameter, the other from 24 in. to 60 in. in diameter. It is adjusted from a steel shaft operating iron geared sprockets. The central shaft is operated by a worm screw at one end of the form and the adjustment to any size is quickly and easily made. These forms are furnished in sets, two 8-foot sections of 16 lineal feet to the set. The smaller size can also be furnished in 10 foot sections.

The concrete for the base of the culvert must be deposited first, the form then placed on this base and the concrete for sides and top of culvert deposited around the form. No end plates are furnished with this core. The outside of the form is 16-gauge galvanized steel and all parts are steel and malleable. This core is easily and quickly adjusted to any size within its range.

Figure 50. Concrete arch bridge on the P. C. C. & St. L. Railroad, Columbus, Ohio, built in 1909. The flood at this point was of such a character that the brick pavement underneath the bridge was entirely washed away leaving only the concrete foundations.

Specifications for Concrete Bridges

Materials

1. Cement. The cement shall meet the requirements of the Standard Specifications for Portland Cement of the American Society for Testing Materials or the United States Government Specification for Portland Cement, Circular No. 33, Bureau of Standards.

2. Fine Aggregate for Concrete. Fine aggregate shall consist of sand, crushed stone or gravel screenings, graded from fine to coarse and passing, when dry, a screen having one-quarter (¼) inch diameter holes; shall be preferably of silicious material, clean, coarse, free from dust, soft particles, loam, vegetable or other deleterious matter, and not more than three (3) per cent shall pass a sieve having one-hundred (100) meshes per linear inch. Fine aggregate shall be of such quality that mortar composed of one (1) part Portland cement and three (3) parts fine aggregate by weight, when made into briquettes will show a tensile strength at least equal to the strength of 1:3 mortar of the same consistency made with the same cement and Standard Ottawa sand. In no case shall fine aggregate containing frost or lumps of frozen material be used.

3. Coarse Aggregate for Concrete. Coarse aggregate shall consist of inert materials such as screened gravel or crushed stone graded in size, passing a 1½-inch screen and retained on a screen having one-quarter (¼) inch diameter holes; shall be clean, hard and durable, free from dust, vegetable or other deleterious matter, and shall contain no soft, flat or elongated particles. In no case shall coarse aggregate containing frost or lumps of frozen material be used.

4. Natural Mixed Aggregates. Natural mixed aggregates shall not be used as they come from the deposit but shall be screened and remixed to agree with the proportions specified.

5. Water. Water shall be clean, free from oil, acid, alkali, or vegetable matter.

6. Reinforcing Metal. The reinforcing metal shall meet the requirements of the Standard Specifications for Steel Reinforcement adopted March 16, 1910, by the American Railway Engineering Association, and shall be free from rust, scale or coatings of any character which will tend to reduce or destroy the bond.*

Construction

7. Forms. Forms shall be substantial, unyielding and so constructed that the concrete will conform to the designed dimensions and contours and shall also be tight to prevent the leakage of mortar. The supports for bridge floors and arches shall remain in place until time for removal as hereinafter specified.

Note:—Unless otherwise specified the steel referred to in this book is what is known as *Manufacturer's Standard Specification, Structural Steel Grade*, commonly known as soft steel.

8. Reinforcement. The reinforcement shall be placed and held in position so that it will not become disarranged during the depositing of the concrete. Whenever it is necessary to splice tension reinforcement, the character of the splice shall be such as will develop its full strength. Splices at the point of maximum stress shall be avoided.

Measuring and Mixing

9. Measuring. The method of measuring the materials for the concrete, including water, shall be one which will insure separate, uniform proportions at all times. A sack of Portland cement (94 lbs. net) shall be considered one (1) cubic foot.

10. Machine Mixing. When the conditions will permit, a machine mixer of a type which insures the uniform proportioning of the materials throughout the mass shall be used. The ingredients of the concrete or mortar shall be mixed to the desired consistency and the mixing shall continue until the cement is uniformly distributed and the mass is uniform in color and homogeneous.

11. Hand Mixing. When it is necessary to mix by hand, the materials shall be mixed dry on a watertight platform until the mixture is of uniform color, the required amount of water added, and the mixing continued until the mass is uniform in color and homogeneous.

12. Retempering. Retempering, that is, remixing mortar or concrete that has partially hardened with additional water, will not be permitted.

Figure 51. Two Concrete Culverts near Rice Lake, Wisconsin. 24-inch diameter; 17-feet long. Built over forms of Concrete Form & Engine Co., at cost of $10.25 each.

Abutments

13. Proportions. The concrete for the abutments shall be mixed in the proportion of one (1) sack Portland cement, two and one-half ($2\frac{1}{2}$) cubic feet of fine aggregate, and five (5) cubic feet of coarse aggregate.

14. Consistency. The materials shall be mixed wet enough to produce a concrete of a consistency that will flow into the forms but which can be conveyed from the mixer to the forms without the separation of the coarse aggregate from the mortar.

15. Placing. The concrete shall be placed in a manner that will permit the most thorough compacting. Where the work is interrupted so that the last layer of concrete shall have hardened before the next can be placed, concrete previously placed shall be roughened, cleansed of foreign material and laitance, drenched and slushed with a mortar consisting of one (1) sack of Portland cement and one and one-half ($1\frac{1}{2}$) cubic feet of fine aggregate. The concrete shall be placed in continuous horizontal layers and vertical joints avoided where possible.

Bridge Floors

16. Proportions. The concrete shall be mixed in the proportion of one (1) sack Portland cement, two (2) cubic feet of fine aggregate, and four (4) cubic feet of coarse aggregate.

17. Consistency. The materials shall be mixed wet enough to produce a concrete of a consistency that will flow into the forms and about

Figure 52. Concrete Culvert, Amherst, Massachusetts. Designed by Massachusetts Highway Commission. 2-foot by 2-foot Opening. 24-foot Roadway. Cost $102.

the metal reinforcement, but which can be conveyed from the mixer to the forms without the separation of the coarse aggregate from the mortar.

18. Placing. The concrete shall be placed in a manner to insure of its being thoroughly worked around the metal reinforcement and into the recesses of the forms. It shall be deposited for the full thickness of the floor and be brought to a surface at the established grade of the bridge floor.

Arches

19. Proportions. The concrete for the arch ring shall be mixed in the proportion of one (1) sack Portland cement, two (2) cubic feet of fine aggregate, and four (4) cubic feet of coarse aggregate.

20. Consistency. The materials shall be mixed wet enough to produce a concrete of a consistency that will flow into the forms but which can be conveyed from the mixer to the forms without the separation of the coarse aggregate from the mortar.

21. Placing. Where possible the concrete for the arch ring shall be deposited in a single day. Where impossible to deposit the concrete in a day, the arch ring shall be divided into transverse sections, each section taken as a day's work. The concreting shall commence either at the crown or at the springing line. In no case shall a joint be made at the crown.

Surface Finish

22. All exposed surfaces shall be finished to have a smooth and neat appearance.

Removal of Forms

23. Time of Removal. In no instance shall any form be removed within less than 48 hours. The supports for slab floors and bridge arches must remain in place at least 28 days. When freezing weather occurs, an extension of time equal to the time structure has been exposed to freezing shall be added to the above.

The bridge shall not be open to traffic and no extraneous loading shall be placed upon the concrete before the removal of the forms.

24. Temperature Below 35 Degrees F. If at any time during the progress of the work there is liability of the temperature dropping to 35 degrees Fahrenheit at night, the water and aggregate shall be heated and precautions taken to protect the work from freezing.

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